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A GRAVITY MODEL DISTRIBUTION OF TRUCK TRIPS IN TWO SMALL CITIES

by 866

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B. S., Colorado State University, 1959

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1965

Approved by:

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INTRODUCTION

Background

This research was sponsored by the Kansas Highway Commission in cooperation with the Civil Engineering Department of Kansas State University at Manhattan, Kansas. The project was conceived as an extension of research conducted by Dr. Bob L. Smith (1)*. Funds were provided for financing the project by the Federal-Aid and Kansas Highway Planning and Research Funds, administered by the Bureau of Public Roads.

The increasing demands for travel facilities in our urban areas have necessitated the application of sound planning principles to solve the associated problems confronting the public highway agencies. In order to make the planning decisions involved, information on the present and expected travel patterns are required. New techniques are needed to aid in gathering this information. Much research and investigation has been made in recent years in the use of mathematical models to synthesize the future travel patterns.

There have been a number of mathematical models developed for use in transportation studies. These models are used to estimate future traffic patterns by incorporating in the model the basic determi-

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* Numbers in parentheses refer to items in the list of references.

nants of the existing traffic pattern. The "gravity model", based on Newton's Universal Law of Gravitation, has had the widest acceptance of all.

The use of the mathematical gravity model for the reproduction of trips by passenger vehicles has received much attention in the recent past with the increased need for efficient planning techniques. However, little research has been conducted in the area of applying the gravity model theory to trucks and other commercial vehicles. Truck trip prediction in the past has often been handled by applying a growth factor method to the existing truck trip configuration. One disadvantage of this procedure is that a supplemental method must be used to estimate future trips from zones which currently produce no trips.

The mathematical gravity model theory, by incorporating information on the traffic configuration, the land use patterns and other social, economic zonal characteristics in a reproducible relationship provides a method of determining the future trip distribution. The parameters which are used in this formulation must be readily obtainable in the present, and predictable in the future. The accuracy of the predicted trip distribution will depend largely on the accuracy with which these parameters can be predicted in the future.

Purpose

The purpose of this research was to develop a mathematical model (the gravity model) that would distribute internal commercial vehicle trips among the various zones in a city in accordance with existing

distributions as measured by origin-destination (O-D) studies. Once the applicability of the gravity model to truck trips was established, the use of the gravity model as a tool for the estimation of the future truck trip distribution was investigated.

Scope

The research was limited to those truck trips in Pittsburg and Hutchinson, Kansas, two study cities, which had both trip ends within the respective study areas. The areas studied are shown in Figs. 1 and 2.

The truck trip information was taken from the comprehensive O. D. survey data and no attempt was made to reduce the sample size, as was the case in Smith's study (1). Two gravity model trip distributions were developed. The first was based on the O. D. survey data of zonal trip productions and attractions while the second was based on zonal productions and attractions in which multiple regression analysis was used to obtain estimating equations based upon zonal characteristics.

Gravity Model Theory

The form of the gravity model (3) used in this study was:

$$T_{i-j} = \frac{P_i A_j F_{i-j} K_{i-j}}{\sum_{x=1}^{n} A_x F_{i-x} K_{i-x}}$$

in which the distribution is normally handled on a basis of various trip

purposes and where:

T_{i-j} = Trips produced in zone i and attracted to zone j.

P_i = Trips produced by zone i.

A_j = Trips attracted by zone j.

F_{i-j} = An empirically derived travel time factor which expresses the average areawide effect of spatial separation on the trip interchange between zones. The measure of distance or spatial separation between zones is usually the total travel time between the centroids of zones i and j. The use of this factor to express the effect of distance between zones upon the zonal trip interchange, rather than the previously used inverse exponential function of time, greatly simplifies the computational requirements of this model. It also provides for the consideration that the effect of spatial separation generally increases as the separation increases, particularly for some trip purposes.

K_{i-j} = A specific zone-to-zone adjustment factor to allow for the incorporation of the effect on travel patterns of defined social or economic linkages not otherwise accounted for in the gravity model formulation.

n = Total number of zones.

In applying the gravity model to trucks, all trips were treated as non-home based trips since the characteristics of truck trips seem to follow a similar pattern to that of the non-home based passenger vehicle trips (1). In this research, for a given zone, truck trip productions were trip origins and attractions were trip destinations.

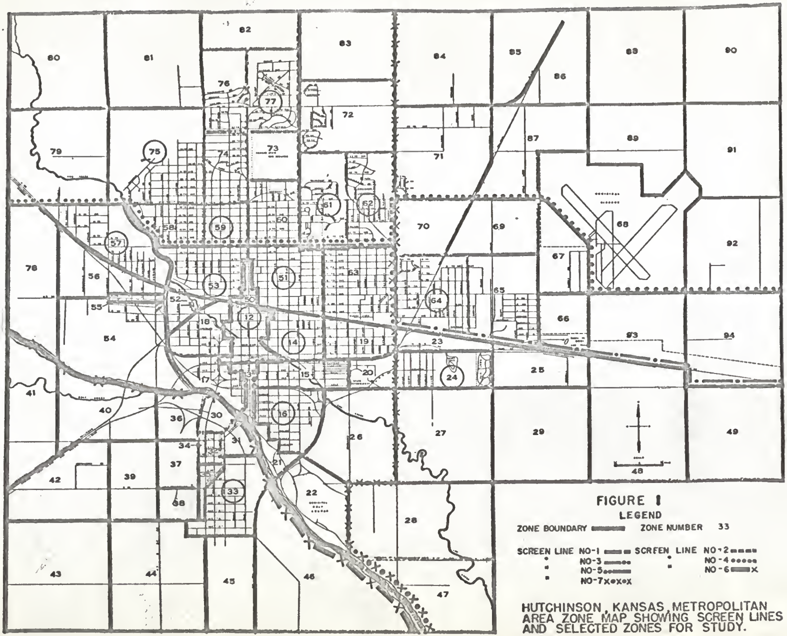
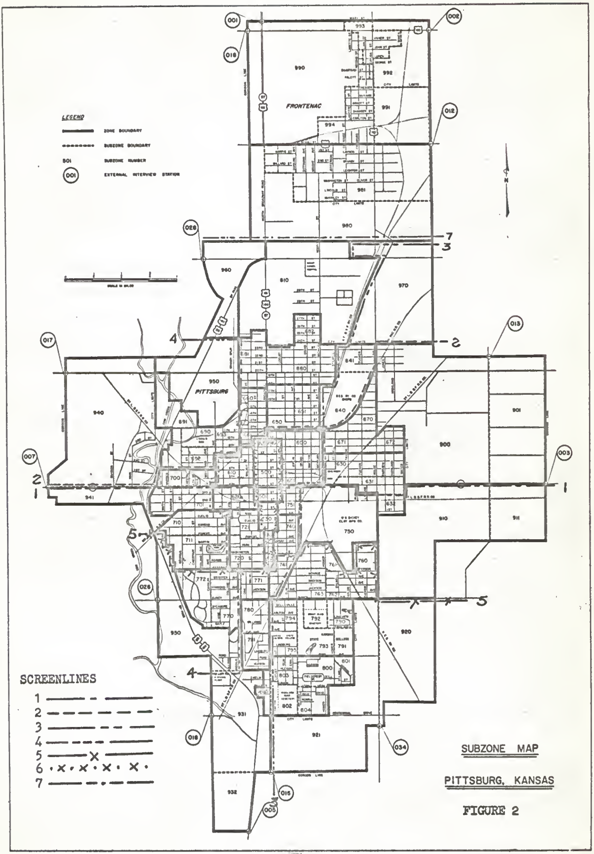


FIGURE 1

HUTCHINSON, KANSAS, METROPOLITAN AREA ZONE MAP SHOWING SCREEN LINES AND SELECTED ZONES FOR STUDY.



SUBZONE MAP

PITTSBURG, KANSAS

FIGURE 2

STUDY PROCEDURE

In order to carry out the objectives of the research, the study was divided into three phases. These were the development of equations to estimate the zonal productions and attractions from zonal characteristics, the reproduction of origin-destination truck trip distribution within desired limits by the gravity model using actual productions and attractions, and the reproduction of origin-destination truck trip distribution using the estimated productions and attractions as input for the gravity model.

The estimating equations were developed through the application of the statistical method of multiple regression analysis to the zonal characteristics obtained from the transportation surveys. This analysis was expedited through the use of the Sixteen-twenty Card Regression Analysis Program (SCRAP) from the IBM computer program library (9).

The reproduction of the O. D. truck trip distribution by the gravity model was achieved with the aid of a 1620 IBM computer and using programs developed by the Computer Section of the Kansas Highway Commission.

The steps followed to complete the study were:

1. The preparation of O. D. data for research use.
2. The development of estimating equations from multiple regression analysis for zonal trip productions and attractions.
3. The application of the gravity model using O. D. survey data trip productions and attractions.

4. The application of the gravity model using estimated trip productions and attractions.

5. The analysis of results.

An examination of the performance of each of these steps will be made in the remainder of the paper.

Descriptions of Study Cities

The two small cities selected for use in this research were Hutchinson and Pittsburg, Kansas. These two cities were chosen since they were typical of the small cities in Kansas and both had been the subjects of transportation studies (4, 5). These studies included both comprehensive internal origin-destination surveys and land use studies, thereby providing all the information necessary for the gravity model research.

The city of Hutchinson had a population of 37, 873 in 1961 with a population of approximately 41, 000 for the metropolitan area. At this time it ranked fifth in population for the metropolitan centers of the State. Of all the small cities of the State, it was surpassed only by Salina in population.

The Hutchinson, Kansas origin-destination survey was conducted in 1959 by the Kansas Highway Commission in cooperation with the City of Hutchinson. The O. D. survey was made in accordance with the standard procedures prescribed by the Bureau of Public Roads. The home interview survey was made on a 20 per cent sample basis. There were about 1, 740 trucks in Hutchinson making approximately 11, 480 internal trips.

Information from this origin-destination study along with data from the land use study was used in this research. The grouping of land use as employed in Hutchinson is listed below:

Residential
Manufacturing
Retail Trade
Wholesale and warehouse
Transportation
Construction
Personal, business, repair services and office
Government and utility
Other open space - streets, alleys, lakes
Recreation and institution

These groups were tabulated in 1000's of square feet.

The population of Pittsburh in 1960 was 18, 678 while the Pittsburg metropolitan area, i. e., including Frontenac, had a population of 20, 391 as of that date. Of the metropolitan centers, Pittsburg ranked tenth in the state in population in 1960.

The comprehensive transportation study was conducted in Pittsburg in the summer of 1961, with the land use survey following in the spring of 1962. These studies were made by a consultant for the City of Pittsburg in cooperation with the Kansas Highway Commission. The O. D. survey was conducted in accordance with Bureau of Public Roads standards, using a 25 per cent sample on the dwelling unit portion of the survey. The truck survey was taken on a 1 in 3 sample. There were approximately 1, 170 trucks making 7, 100 internal trips in Pittsburg.

The O. D. data and the land use information derived from these studies were both used in this study as were the Hutchinson data. The

land use groupings used in Pittsburg were as follows:

Residential
Commercial
Industrial
Public and semi-public
Streets - alleys and railroads
Agriculture and vacant

These values were listed in 1000's of square feet.

Preparation of Data

With both cities, the data from the origin-destination survey had been placed on machine punch cards for the transportation studies conducted on both cities. The truck trip cards, designated Card 4, contained the following information: the sample number which was in fact the license plate number of the truck, the truck capacity, the industry and business in which the truck was used, the vehicle type, the total trips in the area for that day and the number of the trip, the zones of origin and destination, the land uses of the origin and destination, and the trip expansion factor. The required tabulations or summations of data were then conducted by machine processing these data cards.

Classification of Trips by Vehicle Type

With the gravity model studies conducted on passenger cars, the trips are generally grouped according to the trip purpose (1). However, with the truck trips no distinction of trip purpose was made. Originally, it was felt that some grouping of trips would be necessary in order to adequately reproduce the truck trip distribution. The logical choices available were to group by vehicle type or by the industry in which the

truck was used. Since the grouping by industry with its ten classes gave extremely small numbers of trips from some zones, the grouping by vehicle type was chosen.

Initially, the grouping by trucks was set up for three vehicle classes, those being: pickups, panels and other small trucks in the first class, the medium trucks in the second class, and the heavy trucks including tractor-trailers in the third class. This presented the problem of small magnitudes of trips from many of the zones so the classification was finally limited to two groups. The first group included pickups, panels and other small trucks normally classified as vehicle type two by the Planning Department of the Kansas Highway Commission. The second group was composed of all other trucks not included in the preceding description.

By grouping the trips in the manner previously discussed, there was no need to link trips as is sometimes desirable with passenger cars (1). The vehicle type is a constant characteristic, thus eliminating the need for linking.

Data Preparation for Development of Estimating Equations

The information on zonal characteristics had been assimilated and compiled for the transportation studies previously conducted in the two cities, (1, 2). Those factors which were believed to affect the production and attraction of truck trips in a zone were tabulated. This included data on the areas of various land uses in each zone, the population per zone, the number of jobs in each zone, the number of registered cars per zone, the number of dwelling units found in each zone, and the total area of the zone. This information had been gathered

for each of the 83 zones in Hutchinson, but was only available on the basis of 33 zones in Pittsburg. These 33 zones were subdivided to give 82 sub-zones for the traffic analysis in the Pittsburg transportation study. Tabulations of the zonal characteristics for Hutchinson and Pittsburg are given in Tables 1 through 4.

The land use study in Hutchinson utilized 10 major land use categories as previously listed on page 9. These were given in 1000's of square feet. Early in the research it was decided to combine related land use groups and use these combined groups in the development of the estimating equations. This consolidation of groups was made to ease the problems associated with predicting future land use configurations. The land use classes as finally combined were:

Residential
Industrial
Commercial and Public
Open Space
Streets and Alleys

The residential land use group was transferred to the new classification without change. However, the new industrial land use class was formed by combining the manufacturing, transportation and construction land use groups since these groups tend to have similar characteristics concerning truck trips. Retail trade; Wholesale and Warehousing; Personal, Business, Repair Services and Office; Government and Utility; and Recreation and Institution were also grouped under one class: Commercial and Public Use. This grouping encompasses a variety of land use types, however, the truck trip characteristics exhibited by this class are expected to be relatively consistent. The Open Space Group

TABLE 1

HUTCHINSON
ZONAL CHARACTERISTICS

Zone	Total Persons	Dwelling Units	Total Cars	Total Jobs	Area/DU (Sq. Ft.)
12	341	293	156	5,000	2,300
13	143	66	36	614	6,110
14	1,695	754	588	361	5,402
15	975	337	224	32	8,601
16	1,343	434	374	197	8,602
17	398	164	72	169	8,710
18	1,410	541	325	615	6,403
19	1,398	464	457	175	7,797
20	---	---	---	72	---
21	---	---	---	9	---
22	---	---	---	3	---
23	26	15	15	226	6,140
24	864	270	347	21	11,301
25	---	---	---	171	12,500
26	---	---	---	---	12,500
27	134	40	60	19	16,380
28	114	25	35	4	15,450
29	10	5	5	4	12,500
30	---	---	---	45	---
31	---	---	---	90	---
32	174	55	70	73	11,150
33	1,080	298	358	56	13,799
34	15	5	5	127	12,500
35	61	35	15	130	23,350
36	81	41	41	15	2,610
37	---	5	---	---	---
38	---	---	---	5	---
39	132	41	56	12	22,280
40	36	10	10	184	12,500
41	---	---	---	3	---
42	234	81	132	11	34,560
43	36	15	10	4	12,500
44	41	10	15	4	12,500
45	178	46	66	6	14,950
46	20	5	15	---	12,500
47	---	---	---	---	---
48	30	5	5	---	12,500
49	---	---	---	---	---
50	144	117	58	1,150	1,630
51	3,573	1,472	1,236	766	1,126
52	112	32	21	100	7,850
53	2,319	966	778	437	5,799

TABLE 1 (Cont.)

HUTCHINSON
ZONAL CHARACTERISTICS

Zone	Total Persons	Dwelling Units	Total Cars	Total Jobs	Area/DU (Sq. Ft.)
54	401	133	138	---	12,460
55	70	32	48	146	17,410
56	324	94	125	153	16,460
57	840	313	349	99	13,601
58	1,414	534	567	65	10,002
59	1,576	603	551	166	5,701
60	2,387	861	1,021	190	1,311
61	986	357	402	251	7,799
62	1,524	413	454	61	10,302
63	3,470	1,163	1,151	513	2,969
64	1,781	574	575	155	1,775
65	265	90	96	604	7,500
66	---	---	---	809	---
67	243	64	79	50	29,130
68	---	---	---	85	---
69	---	---	---	62	---
70	---	---	---	---	---
71	621	171	203	17	37,620
72	258	91	111	69	13,500
73	---	---	---	234	---
74	1,890	655	855	123	1,835
75	2,157	698	854	163	1,153
76	869	258	400	78	15,298
77	1,471	495	676	76	5,188
78	102	31	87	13	36,970
79	92	31	61	18	26,670
80	19	5	5	3	12,500
81	38	14	19	11	12,500
82	---	---	---	1	---
83	46	10	10	7	12,500
84	256	67	87	7	18,880
85	200	46	82	84	32,790
86	---	---	---	19	---
87	188	55	89	59	20,710
88	31	5	10	---	12,500
89	30	10	15	1	12,500
90	---	---	---	---	---
91	---	---	---	2	---
92	94	25	30	9	12,500
93	35	5	10	6	12,500
94	69	15	15	15	12,500

TABLE 2
HUTCHINSON
LAND USE AREA BY ZONE
(In 1000's of Square Feet)

Zone	Residential	Industrial	Commercial & Public	Open Space	Total Area (Including Streets And Alleys)
12	602	1,461	3,919	86	8,706
13	367	730	610	166	2,962
14	4,380	483	550	57	7,973
15	3,690	534	433	1,220	8,126
16	4,526	2,506	270	34	10,012
17	1,531	3,185	545	938	7,779
18	3,158	1,269	595	120	7,423
19	4,331	910	461	0	7,975
20	0	570	3,963	0	5,001
21	667	0	1,985	700	3,647
22	0	138	13,734	1,525	15,733
23	573	4,138	50	14	5,119
24	3,338	4,300	215	1,963	10,829
25	0	4,682	1,787	5,126	12,120
26	0	752	20,762	318	22,500
27	655	45	915	25,580	27,878
28	340	0	480	26,615	28,080
29	0	0	0	27,248	27,878
30	17	520	410	1,839	3,281
31	14	556	557	1,656	3,224
32	1,032	0	92	0	1,778
33	6,079	6	405	2,879	13,327
34	112	0	253	30	600
35	472	82	400	174	1,980
36	107	480	346	5,953	7,123
37	77	0	0	5,001	5,298
38	255	0	531	3,860	4,870
39	1,340	252	128	9,155	11,449
40	80	8,410	0	10,646	19,395
41	0	2	31	17,609	17,968
42	3,456	960	42	12,696	18,032
43	0	0	0	32,312	32,946
44	168	370	10	29,148	30,455
45	4,882	0	51	8,512	14,606
46	36	1,508	90	37,775	39,717
47	0	0	0	23,756	24,117
48	0	541	0	33,837	35,192
49	0	0	0	27,248	27,878
50	150	104	1,052	0	1,949
51	7,883	175	1,166	0	13,484
52	632	596	1,349	265	3,307
53	6,546	203	1,105	110	11,403

TABLE 2 (Cont.)

Zone	Residential	Industrial	Commercial & Public	Open Space	Total Area (Including Streets And Alleys)
54	10,682	894	619	15,459	28,592
55	892	187	1,191	87	2,682
56	6,245	1,105	878	1,213	9,989
57	8,509	54	109	4,050	14,590
58	5,010	78	656	0	7,818
59	3,339	0	585	0	6,018
60	6,312	0	1,142	0	10,398
61	2,916	7	8,561	525	13,600
62	7,841	115	690	2,652	13,777
63	8,693	1,320	1,488	42	16,292
64	8,270	2,339	2,667	649	17,837
65	4,402	11,275	696	12	21,436
66	0	4,994	0	3,271	8,453
67	2,023	194	90	44,064	46,976
68	0	43,654	1,966	15	46,331
69	0	3,915	2	7,794	8,983
70	0	0	2	11,305	11,530
71	5,937	0	184	18,946	26,579
72	6,068	94	483	11,294	19,594
73	0	8	6,615	0	7,182
74	6,670	15	507	0	10,023
75	9,606	0	789	14,272	28,392
76	4,606	0	912	267	7,295
77	9,856	0	986	84	13,370
78	1,220	193	87	18,489	20,453
79	7,465	190	75	19,475	27,878
80	2,180	0	0	25,216	27,878
81	2,303	0	25	24,554	28,015
82	0	0	0	11,397	11,711
83	174	0	0	20,341	20,909
84	3,379	125	235	22,691	27,878
85	1,869	0	4,879	6,218	13,905
86	0	630	2,118	10,452	13,973
87	1,512	667	351	18,567	22,213
88	0	0	4,739	22,745	27,878
89	280	0	0	20,343	21,005
90	60	0	1,394	25,948	27,878
91	135	0	0	26,137	26,910
92	1,381	0	60	24,845	27,515
93	0	90	242	19,867	20,596
94	345	2,347	2,007	17,432	22,883

TABLE 3

PITTSBURG
ZONAL CHARACTERISTICS

Zone	Total Persons	Dwelling Units	Total Cars	Total Jobs	Area/DU (Sq. Ft.)
50	393	272	145	2,095	1,409
60	1,060	380	320	230	5,454
61	647	280	242	65	5,475
62	429	172	204	305	5,926
63	992	387	415	125	8,615
64	148	57	50	275	7,886
65	1,100	387	424	95	7,141
66	231	100	101	320	5,645
67	980	344	321	20	9,087
68	1,783	674	667	100	8,628
69	888	308	301	20	7,390
70	956	388	355	45	7,041
71	1,309	438	523	55	9,750
72	1,002	373	391	80	7,097
73	289	136	130	560	3,161
74	814	308	288	20	6,644
75	238	65	65	560	3,806
76	851	315	296	15	11,151
77	948	344	468	80	14,182
78	720	215	300	80	9,713
79	1,878	781	744	470	2,033
80	1,304	444	560	30	8,168
81	415	145	179	325	21,948
90	555	165	196	10	14,097
91	77	25	34	5	10,768
92	67	25	39	15	13,660
93	0	0	0	55	0
94	212	64	92	140	16,028
95	24	5	8	10	23,080
96	16	8	12	0	18,838
97	29	13	8	0	13,369
98	1,396	492	548	120	17,705
99	725	259	226	75	13,880

TABLE 4
PITTSBURG
LAND USE AREA BY ZONE
(In 1000's of Square Feet)

Zone	Residential	Industrial	Commercial & Public	Open Space	Total Area (Including Streets And Alleys)
50	383	153	1,648	230	3,833
60	2,073	531	319	53	5,314
61	1,533	0	514	28	2,788
62	1,019	249	45	23	2,265
63	3,334	155	930	620	7,754
64	450	4,795	225	824	7,492
65	2,763	0	779	53	5,314
66	565	565	247	741	3,528
67	3,126	0	0	1,427	6,795
68	5,815	0	349	1,745	11,630
69	2,276	91	3,004	2,276	9,104
70	2,732	0	167	725	5,576
71	4,271	75	525	824	7,492
72	2,647	45	224	90	4,487
73	430	143	594	82	2,047
74	2,046	114	190	114	3,790
75	247	7,794	0	1,113	12,371
76	3,513	0	98	3,025	9,757
77	4,879	0	261	1,481	8,712
78	2,088	44	133	711	4,443
79	1,588	0	6,351	953	10,585
80	3,626	0	2,254	1,372	9,801
81	3,183	0	1,224	18,850	24,481
90	2,326	0	0	43,730	46,522
91	269	0	0	26,651	26,920
92	342	0	1,708	31,761	34,151
93	0	581	291	27,602	29,055
94	1,026	342	342	31,801	34,195
95	115	0	0	11,313	11,543
96	151	0	0	7,310	7,492
97	174	0	0	17,033	17,380
98	8,711	0	792	25,737	39,596
99	3,595	0	2,054	39,545	51,357

remained as the Open Space class without any addition. The Street and Alley group also formed a class.

In Pittsburg, the land use groups were also consolidated to fit this general classification. This was accomplished by combining into the Commercial and Public Use class the Commercial and Public and Semi-Public groups since the remainder of the land use grouping already compiled with this classification.

Development of Estimating Equation

The development of estimating equations in most gravity model studies for passenger cars has been divided into two phases, those for productions and those for attractions. An examination of the productions and attractions for each zone indicated that for truck trips the number of productions and attractions for any zone were nearly always of the same magnitude.

An examination of the nature of truck trips within a city indicates that this is reasonable. A truck naturally begins its circuit in the zone in which it was housed the previous night. This zone would tally one origin, or production. The first delivery or stop would constitute the destination, or attraction, for this first trip, giving the zone in which this occurred a tally of one destination. With the truck's departure from this initial stop, the second zone tallies one origin. Thus for each delivery or stop, the zone in which it occurs tallies one destination and one origin. After completing the required business for the day, the truck would return to the zone in which it was housed balancing the previously tallied origin with one destination. The origins and destinations

would not balance if the truck terminated its day in a zone in which it was not housed the previous night. This partially explains the slight variations found in the productions and attractions as determined from the O. D. data.

Since the study was concerned with internal truck trips, those having one trip end outside the cordon line were not considered. Some of the variation between productions and attractions in any given zone can also be accounted for by those trucks housed inside the study area which enter the area from outside. If the truck enters the study to make a stop in Zone A and then departs without making another stop within the study area or remains in this location in Zone A, the trips would not be considered. But, if the truck leaves Zone A and stops in Zone B before leaving the study area, one origin would be tallied in Zone A and one destination in Zone B contributing to the discrepancies found between the productions and attractions. See Table 5.

Because of this relation of productions and attractions with truck trips, only one set of estimating equations was developed for productions and attractions. The set consisted of three groups of estimating equations based on the productions and attractions for all trucks combined, for small trucks, and for medium and large trucks as previously defined.

The variables used in the development of these equations were factors which were felt to have some possible relation to the truck trip production and attraction. Further, consideration was given to the ease with which these factors could be predicted in the future. The dependent variables were trips produced, or attracted, per zone.

TABLE 5

O-D PRODUCTIONS AND ATTRACTIONS
FOR ALL TRUCKS

HUTCHINSON						PITTSBURG					
Zone	Prod.	Attr.	Zone	Prod.	Attr.	Zone	Prod.	Attr.	Zone	Prod.	Attr.
12	2,082	2,066	56	66	66	500	716	710	772	50	50
13	471	477	57	104	93	501	310	310	780	125	119
14	186	186	58	159	159	502	195	198	781	60	66
15	99	99	59	110	104	600	168	162	790	23	26
16	137	142	60	356	356	601	274	277	791	---	---
17	60	55	61	121	126	610	142	145	792	---	3
18	334	334	62	132	132	620	92	92	793	13	13
19	329	334	63	592	603	630	145	142	794	76	76
20	93	93	64	296	290	631	116	112	795	109	106
21	11	16	65	312	312	632	26	30	800	125	125
22	---	---	66	164	164	640	53	50	801	7	3
23	137	142	67	77	77	641	7	7	802	7	7
24	99	93	68	77	82	650	73	63	803	135	142
25	44	44	69	44	44	651	66	66	804	53	53
26	---	---	70	5	11	660	63	59	805	26	26
27	38	38	71	71	71	661	201	201	810	191	195
28	5	16	72	82	82	670	26	26	811	---	---
29	---	---	73	121	126	671	69	73	900	43	46
30	5	5	74	307	296	672	43	43	901	30	30
31	88	88	75	247	252	680	238	234	910	---	---
32	99	99	76	153	148	681	119	106	911	3	3
33	93	93	77	197	203	682	33	33	920	10	10
34	44	44	78	5	5	690	7	7	921	---	---
35	137	132	79	5	5	691	---	---	930	3	3
36	5	5	80	5	5	692	73	76	931	69	69
37	5	5	81	5	5	693	76	76	932	---	---
38	---	---	82	---	---	700	113	119	940	33	26
39	27	22	83	---	---	701	69	69	941	26	23
40	38	33	84	71	71	710	79	83	950	99	99
41	16	22	85	44	44	711	116	116	960	10	10
42	49	49	86	5	5	720	152	152	970	7	7
43	---	---	87	33	33	721	53	56	980	26	23
44	---	---	88	22	22	730	294	294	981	198	201
45	55	55	89	11	11	731	139	135	990	33	40
46	11	11	90	---	---	740	73	76	991	63	56
47	16	16	91	---	---	741	96	92	992	10	10
48	---	---	92	44	49	750	142	142	993	40	43
49	---	---	93	5	---	751	149	152	994	135	135
50	592	592	94	11	11	760	53	53			
51	1,019	1,008	95	---	---	761	36	40			
52	77	82	96	---	---	762	30	30			
53	690	707				763	86	86			
54	93	82				770	129	132			
55	132	126				771	125	132			

The procedure followed in obtaining the equations ultimately selected as "best" was to include all the variables in the early equations in various forms; then by examining the R^2 and loss in sums of squares for deleting variables in the equations, the significance of various variables was estimated. The coefficient of determination, R^2, is indicative of the amount of variability explained by the equation. The loss in sum of squares for a deleted variable measures the relative significance of each of the terms in the estimating equation. After the more useful variables were found, these were combined in equations in the forms of cross products, ratios, or other relationships along with the pure variables in an attempt to further improve the coefficient of determination, and thereby the estimating power of the equations. Analysis of these equations was made on the basis of the loss in sums of squares for deleting a variable as previously described.

From the very outset of this phase of the study, the number of jobs in each zone was found to be a good indicator of productions and attractions. It was further found to be a good indicator when combined with other variables in cross-products, notably population per zone, dwelling units per zone and cars per zone. Along with the variables already mentioned, the areas of various land uses in each zone and the area of the zone were used in a variety of forms. The land use classification of the five general classes described earlier was the basis for the division of land use as employed for the estimating equation development. The results obtained using this combined classification were

better than the original groupings used in the transportation studies. Improved estimating power was noticed with the equations using the ratios of the various land use classes to the total area of the zone.

A factor designed to indicate the amount of development in each zone provided some improvement in the R^2 for the equations. The relation used to determine the factor was:

$$\text{Development factor} = \frac{\text{Total area - area of streets, alleys and open space}}{\text{Total area - area of streets and alleys}}$$

Another factor was considered which was also intended to determine the amount of development in a zone. This factor was based on the ratio of the net area of zone, i. e., the total area minus the area of streets and alleys, to the area of open space.

Gravity Model Application Using Actual Productions and Attractions

The procedure followed in calibrating a gravity model requires the development of the travel time factors mentioned on Page 6 of this report. This is achieved by varying the travel time factors until the travel time frequency distribution given by the O. D. data is reproduced within the desired limits. The travel time factors are expected to reflect the effect of variations in trip travel time versus trip frequency for trips made in the area. The travel times were determined by adding the terminal time for the zone on each end of the trip to the minimum driving time between those zones as found in the "time trees". "Time trees" are the tabulation of the minimum zone- to-zone driving times as determined in the traffic assignment process.

The travel time for intrazonal trips was taken as 1.0 minute plus twice the terminal times. The "time trees" do not provide driving time for trips with both ends within the zone. Analysis of this topic was made in reference (1) which indicated 1.0 minute to be a reasonable intrazonal driving time in Hutchinson. After a similar analysis, 1.0 minute terminal times were found to be reasonable for Pittsburg also. The zonal trip productions and attractions were known for each zone. For the cities studied, the zone-to-zone adjustment factors, K_{ij}, were taken as 1.0 for all zones. The determination of the travel time factors, knowing the truck trip distribution, requires a trial and error solution which was expedited with the use of a computer program.

The development of the travel time factors was accomplished by first assuming a set of factors and then determining the truck trip distribution by the gravity model formula. The travel time frequency distribution for the truck trip configuration was then found by accumulating the number of trip interchanges within each one minute increment of travel time and expressing them as a percentage of the total trips. This was compared with the travel time frequency distribution obtained from the O. D. data. Three comparisons were made in testing the accuracy of the frequency distribution. The first comparison made was an examination of graphs of the travel time frequency distributions. The graph of the travel time frequency distribution for the computed trip configuration must approximate that of the O. D. data. Secondly, the average travel time for the computed data should be

within ± 5 per cent of the O. D. data (3). The third comparison was the degree of agreement of the total truck minutes of travel between the two sets of data, which should also be within ± 5 per cent to be satisfactory. The total truck minutes were found by multiplying the number of truck trips, in each 1-minute travel time increment, by the travel time.

If the gravity model results did not satisfy the above comparisons, the travel time factors were adjusted. This adjustment was made for each of the travel time factors by multiplying the travel time factor by the ratio of the percentage of trips in the increment for the O. D. data to the percentage of trips from the computed trip configuration.

The Computer Section of the Kansas Highway Commission modified the existing computer program (1, 2) to determine the travel time frequency based on total travel time, including terminal times in origin and destination zones, rather than only travel time between zones. A new computer program was written which performed the entire development of travel time factors. The input for this program was the "time trees", the zonal productions, the zonal attractions, the terminal times, the initial travel time factors, the travel time frequency distribution for the O. D. data, the average O. D. travel time and the total truck minutes of travel from the survey data. The adjustment of the travel time factors was made within the computer, allowing the user to continue these adjustments until the travel time frequency distribution was within the specified limits. When the comparisons were satisfactory, the travel time factors were plotted on a graph and a smooth

curve was drawn through the points. This set of travel time factors was fed back into the computer, and final zone-to-zone movements were computed. Four or five passes were normally required to satisfactorily reproduce the O. D. travel time frequency distribution.

The gravity model was applied to two sets of data. The first was based on the two classifications of vehicle type: pickups, panels, and small trucks in one group and all other trucks in the other. With the second, all truck trips were considered as one group. The first set of the small truck data gave satisfactory results, however, the data for the large trucks did not give results which were entirely satisfactory. The major reasons for this were felt to be the small numbers of trips made from some zones with a number of zones showing no truck trips at all for large trucks. The results obtained when all trucks were considered in one group were within the desired limits.

A number of gravity model applications were conducted with different terminal times. The terminal times considered were as follows:

1. 3.0, 2.5, 2.0 and 1.5 minutes in CBD zones, zones adjacent to the CBD, other zones which were highly developed, and the zones which were undeveloped, respectively,. The CBD zones in Hutchinson were numbers 12, 13 and 50. In Pittsburg they were 500, 501 and 502.

2. 3.0, 2.0, 1.0, and 0.0 minutes applied in the same manner as given above.

3. 1.0 minutes in all zones.

4. No terminal times.

Gravity Model Application Using Estimated Productions and Attractions

After the validity of applying the mathematical gravity model to trucks had been verified using the actual trip productions and attractions as determined from the O. D. data, the gravity model was then applied using estimated productions and attractions.

The input parameters of trip productions and attractions were determined from the best estimating equations developed. Travel time factors previously developed in this study were used and the results were within the limits. Comparisons with the O. D. results were made as described in the previous section of this report.

ANALYSIS OF RESULTS

The development of the estimating equations by the multiple regression analysis provided a method for estimating the trip productions and attractions for each zone. Those factors found to contribute substantially to the estimation of truck trip productions and attractions were included in the regression equations.

The truck trip distribution for the O. D. data was first reproduced using the trip productions and attractions determined from the O. D. survey data. Travel time factors were developed which when plotted versus travel time gave a smooth curve for both Hutchinson and Pittsburg. The use of O. D. productions and attractions served to prove the validity of the mathematical gravity model when applied to truck trips.

The gravity model was also applied using the trip productions and attractions for each zone as determined by the multiple regression equations. This was done to ascertain the ability of the gravity model to estimate the truck trip distribution. The use of (1) the trip productions and attractions as estimated from the regression equations and (2) the travel time factors developed when the gravity model was "calibrated" on the O. D. data, is the procedure one would follow to predict truck trips. However, to facilitate the testing of results, estimated current trip productions and attractions were used and the checks were made against current O. D. data.

Estimates of Trip Production and Attraction

The estimating equations which were developed from the application of the multiple regression technique are listed in Table 6. Estimating equations were developed for all trucks combined, small trucks designated as vehicle Type 2, and medium and large trucks designated as vehicle Type 3 for this section of the study.

One important test of the estimating power exhibited by the estimating equation was R^2, the coefficient of multiple determination. This is the square of the correlation coefficient, R. The coefficient of multiple determination, R^2, measures the goodness or fit of the regression. It is a measure of the amount of variability explained by the regression equation. Although the R^2 values for the estimating equations were large, the magnitudes of the total sums of squares were also large. Consequently, a substantial amount of variability was noted in the results. The R^2 values are tabulated in Table 7.

TABLE 6

ESTIMATING EQUATIONS FROM MULTIPLE REGRESSION ANALYSIS

Equation No. 1 - HRA 8306 D2 - Hutchinson - All Trucks

$$\begin{aligned}Y = {} & 2.2550\text{x}10^{2} + 7.1408\text{x}10^{-2}\ \text{Pop} - 8.3073\text{x}10^{-1}\ \text{DU} + 5.8973\text{x}10^{-1}\ \text{Cars} \\ & + 4.1061\text{x}10^{-1}\ \text{Jobs} - 1.3597\text{x}10^{5}\ 1/A_T - 2.1368\text{x}10^{2}\ \text{LUR}/A_T - 2.0727\text{x}10^{2}\ \text{LUI}/A_T \\ & - 2.0325\text{x}10^{2}\ \text{LUC}/A_T - 2.1803\text{x}10^{2}\ \text{LUOS}/A_T + 1.4809\text{x}10\ \text{OSF}/A_T + 1.0873\text{x}10^{5}\ \text{DF}/A_T \\ & + 4.3332\text{x}10^{-4}\ (\text{Pop x DU}) - 4.0806\text{x}10^{-4}\ (\text{Pop x Cars}) - 1.9700\text{x}10^{-6}\ (\text{Pop x Jobs}) \\ & + 4.2089\text{x}10^{-4}\ (\text{DU x Cars}) + 6.2880\text{x}10^{-4}\ (\text{DU x Jobs}) - 1.1411\text{x}10^{-3}\ (\text{Cars x Jobs})\end{aligned}$$

Y = Truck Trips/Zone

Equation No. 2 - PRA 3306 D2 - Pittsburg - All Trucks

$$\begin{aligned}Y = {} & 3.9112\text{x}10^{2} - 8.6221\text{x}10^{-1}\ \text{Pop} + 1.2289\text{x}10\ \text{DU} + 1.8363\text{x}10\ \text{Cars} + 5.5463\text{x}10^{-1}\ \text{Jobs} \\ & + 4.5261\text{x}10^{4}\ 1/A_T - 7.7591\text{x}10^{2}\ \text{LUR}/A_T - 7.5875\text{x}10^{2}\ \text{LUI}/A_T - 4.2005\text{x}10^{2}\ \text{LUC}/A_T \\ & - 3.8185\text{x}10^{2}\ \text{LUOS}/A_T - 3.8246\text{x}10^{3}\ \text{OSF}/A_T + 2.8037\text{x}10^{5}\ \text{DF}/A_T + 1.6799\text{x}10^{-4}\ (\text{Pop x DU}) \\ & + 2.7226\text{x}10^{-4}\ (\text{Pop x Cars}) + 4.5130\text{x}10^{-3}\ (\text{Pop x Jobs}) - 1.4544\text{x}10^{-3}\ (\text{DU x Cars}) \\ & - 4.7031\text{x}10^{-4}\ (\text{DU x Jobs}) - 1.2418\text{x}10^{-2}\ (\text{Cars x Jobs})\end{aligned}$$

Y = Trucks Trips/Zone

TABLE 6 (Cont.)

ESTIMATING EQUATIONS FROM MULTIPLE REGRESSION ANALYSIS

Equation No. 3 - RA 11606 D2 - Hutchinson & Pittsburg Comb. - All Trucks

$$Y = 4.3660\times10^{2} - 1.7250\times10^{-1}\ Pop - 5.7755\times10^{-1}\ DU + 1.1130\ Cars + 4.3855\times10^{-1}\ Jobs$$
$$- 1.8051\times10^{5}\ 1/A_T - 5.2505\times10^{2}\ LUR/A_T - 4.6211\times10^{2}\ LUI/A_T - 4.0162\times10^{2}\ LUC/A_T$$
$$- 4.2009\times10^{2}\ LUOS/A_T - 2.9407\times10\ OSF/A_T + 1.1287\times10^{5}\ DF/A_T + 5.9653\times10^{-4}\ (Pop \times DU)$$
$$- 3.6990\times10^{-4}\ (Pop \times Cars) + 3.2232\times10^{-4}\ (Pop \times Jobs) - 1.1526\times10^{-4}\ (DU \times Cars)$$
$$+ 1.0031\times10^{-3}\ (DU \times Jobs) - 2.8169\times10^{-3}\ (Cars \times Jobs)$$

Y = Truck Trips/Zone

Equation No. 4 - HRA 8306 D2 - Hutchinson - V.T. 2 (Pickups, Panels and Small Trucks)

$$Y = 1.7416\times10^{2} - 1.2600\times10^{-4}\ Pop - 3.9723\times10^{-1}\ DU + 4.0501\times10^{-1}\ Cars + 2.3149\times10^{-1}\ Jobs$$
$$- 1.2982\times10^{5}\ 1/A_T = 1.6987\times10^{2}\ LUR/A_T - 1.7494\times10^{2}\ LUI/A_T - 1.4429\times10^{2}\ LUC/A_T$$
$$- 1.6398\times10^{2}\ LUOS/A_T + 7.7833\ OSF/A_T + 1.1078\times10^{5}\ DF/A_T + 2.5967\times10^{-4}\ (Pop \times DU)$$
$$- 2.2087\times10^{-4}\ (Pop \times Cars) - 1.4406\times10^{-4}\ (Pop \times Jobs) + 2.3620\times10^{-4}\ (DU \times Cars)$$
$$+ 7.7505\times10^{-4}\ (DU \times Jobs) - 6.8805\times10^{-4}\ (Cars \times Jobs)$$

Y = Small Truck Trips/Zone

TABLE 6 (Cont.)

ESTIMATING EQUATIONS FROM MULTIPLE REGRESSION ANALYSIS

Equation No. 5 - PRA 3306 D2 - Pittsburg - V.T. 2

$$Y = 2.5727\times10^{2} - 6.0223\times10^{-1}\ \mathrm{Pop} + 8.6892\times10^{-1}\ \mathrm{DU} + 1.1159\ \mathrm{Cars} + 3.9909\times10^{-1}\ \mathrm{Jobs}$$
$$+ 1.8360\times10^{5}\ 1/A_T - 4.3203\times10^{2}\ \mathrm{LUR}/A_T - 4.6252\times10^{2}\ \mathrm{LUI}/A_T - 2.4973\times10^{2}\ \mathrm{LUC}/A_T$$
$$- 2.6787\times10^{2}\ \mathrm{LUOS}/A_T - 7.2367\times10\ \mathrm{OSF}/A_T - 2.6926\times10^{5}\ \mathrm{DF}/A_T + 3.0201\times10^{-4}\ (\mathrm{Pop}\times\mathrm{DU})$$
$$+ 1.0530\times10^{-4}\ (\mathrm{Pop}\times\mathrm{Cars}) + 2.8524\times10^{-3}\ (\mathrm{Pop}\times\mathrm{Jobs}) - 1.1741\times10^{-3}\ (\mathrm{DU}\times\mathrm{Cars})$$
$$- 1.5994\times10^{-4}\ (\mathrm{DU}\times\mathrm{Jobs}) - 8.0787\times10^{-3}\ (\mathrm{Cars}\times\mathrm{Jobs})$$

Y = Small Truck Trips/Zone

Equation No. 6 - RA 11606 D2 - Hutchinson & Pittsburg Combined - V.T. 2

$$Y = 2.7062\times10^{2} - 7.7043\times10^{-2}\ \mathrm{Pop} - 3.5524\times10^{-1}\ \mathrm{DU} + 5.5744\times10^{-1}\ \mathrm{Cars} + 2.6481\times10^{-1}\ \mathrm{Jobs}$$
$$- 1.8051\times10^{5}\ 1/A_T - 5.2505\times10^{2}\ \mathrm{LUR}/A_T - 4.6211\times10^{2}\ \mathrm{LUI}/A_T - 4.0162\times10^{2}\ \mathrm{LUC}/A_T$$
$$- 4.2009\times10^{2}\ \mathrm{LUOS}/A_T - 2.9407\times10\ \mathrm{OSF}/A_T + 1.1287\times10^{5}\ \mathrm{DF}/A_T + 5.9653\times10^{-4}\ (\mathrm{Pop}\times\mathrm{DU})$$
$$- 3.6990\times10^{-4}\ (\mathrm{Pop}\times\mathrm{Cars}) + 3.2232\times10^{-4}\ (\mathrm{Pop}\times\mathrm{Jobs}) - 1.1526\times10^{-4}\ (\mathrm{DU}\times\mathrm{Cars})$$
$$+ 1.0031\times10^{-3}\ (\mathrm{DU}\times\mathrm{Jobs}) - 2.8169\times10^{-3}\ (\mathrm{Cars}\times\mathrm{Jobs})$$

Y = Small Truck Trips/Zone

TABLE 6 (Cont.)

ESTIMATING EQUATIONS FROM MULTIPLE REGRESSION ANALYSIS

Equation No. 7 - HRA 8306 D2 - Hutchinson - V.T. 3 (Medium and Large Trucks)

$$Y = 5.2637\text{x}10 + 6.8799\text{x}10^{-2}\ \text{Pop} - 4.2026\text{x}10^{-1}\ \text{DU} + 1.7681\text{x}10^{-1}\ \text{Cars} + 1.7815\text{x}10^{-1}\ \text{Jobs}$$
$$- 9.9946\text{x}10^{3}\ 1/A_T - 4.5120\text{x}10\ \text{LUR}/A_T - 3.4062\text{x}10\ \text{LUI}/A_T - 6.0530\text{x}10\ \text{LUC}/A_T$$
$$- 5.3318\text{x}10\ \text{LUOS}/A_T + 7.2980\ \text{OSF}/A_T + 1.8497\text{x}10^{3}\ \text{DF}/A_T + 1.7043\text{x}10^{-4}\ (\text{Pop x DU})$$
$$- 1.8049\text{x}10^{-4}\ (\text{Pop x Cars}) + 1.4092\text{x}10^{-4}\ (\text{Pop x Jobs}) + 1.7733\text{x}10^{-4}\ (\text{DU x Cars})$$
$$- 1.4244\text{x}10^{-4}\ (\text{DU x Jobs}) - 4.5338\text{x}10^{-4}\ (\text{Cars x Jobs})$$

Y = Medium and Large Truck Trips/Zone

Equation No. 8 - PRA 3306 D2 - Pittsburg - V.T. 3

$$Y = 1.3379\text{x}10^{2} - 2.6040\text{x}10^{-1}\ \text{Pop} + 3.6030\text{x}10^{-1}\ \text{DU} + 6.7806\text{x}10^{-1}\ \text{Cars} + 1.5551\text{x}10^{-1}\ \text{Jobs}$$
$$- 1.3829\text{x}10^{5}\ 1/A_T - 3.4387\text{x}10^{2}\ \text{LUR}/A_T - 2.9616\text{x}10^{2}\ \text{LUI}/A_T - 1.7026\text{x}10^{2}\ \text{LUC}/A_T$$
$$- 1.1394\text{x}10^{2}\ \text{LUOS}/A_T - 3.7526\text{x}10^{3}\ \text{OSF}/A_T + 5.4963\text{x}10^{5}\ \text{DG}/A_T - 1.3324\text{x}10^{-4}\ (\text{Pop x DU})$$
$$+ 1.6712\text{x}10^{-4}\ (\text{Pop x Cars}) + 1.6613\text{x}10^{-3}\ (\text{Pop x Jobs}) - 2.8290\text{x}10^{-4}\ (\text{DU x Cars})$$
$$- 3.1053\text{x}10^{-4}\ (\text{DU x Jobs}) - 4.3406\text{x}10^{-3}\ (\text{Cars x Jobs})$$

Y = Medium and Large Truck Trips/Zone

TABLE 6 (Cont.)

ESTIMATING EQUATIONS FROM MULTIPLE REGRESSION ANALYSIS

Equation No. 9 - RA 11606 D2 - Hutchinson & Pittsburg Combined - V.T. 3

$$\begin{aligned} Y = {} & 1.6778 \times 10^{2} - 9.7601 \times 10^{-2}\ \text{Pop} - 2.1242 \times 10^{-1}\ \text{DU} + 5.6539 \times 10^{-1}\ \text{Cars} + 1.7259 \times 10^{-1}\ \text{Jobs} \\ & - 4.9514 \times 10^{4}\ 1/A_T - 2.2853 \times 10^{2}\ \text{LUR}/A_T - 1.7245 \times 10^{2}\ \text{LUI}/A_T - 1.6441 \times 10^{2}\ \text{LUC}/A_T \\ & - 1.6339 \times 10^{2}\ \text{LUOS}/A_T - 2.4896 \times 10\ \text{OSF}/A_T + 3.3151 \times 10^{4}\ \text{DF}/A_T + 2.9966 \times 10^{-4}\ (\text{Pop} \times \text{DU}) \\ & - 1.7338 \times 10^{-4}\ (\text{Pop} \times \text{Cars}) + 1.8809 \times 10^{-4}\ (\text{Pop} \times \text{Jobs}) - 2.8488 \times 10^{-4}\ (\text{DU} \times \text{Cars}) \\ & - 7.2607 \times 10^{-5}\ (\text{DU} \times \text{Jobs}) - 7.3938 \times 10^{-4}\ (\text{Cars} \times \text{Jobs}) \end{aligned}$$

Y = Medium and Large Truck Trips/Zone

Note: The variables used were:

Pop - Persons per zone

DU - Total Dwelling Units per zone

Cars - Total cars per zone

Jobs - Total number of jobs per zone

A_T - Total zonal area in 1000's of square feet

LUR - Residential land use area in 1000's of square feet (all land use was measured in 1000's of square feet)

LUI - Industrial land use area

LUC - Commercial and public land use area

TABLE 6 (Cont.)

ESTIMATING EQUATIONS FROM MULTIPLE REGRESSION ANALYSIS

LUOS - Open space land use area

OSF - Open space factor = $\frac{\text{Total Area - Area of Streets and Alleys}}{\text{Area of Open Space}}$

DF - Development factor = $\frac{\text{Total Area - Area of Streets, Alleys \& Open Space}}{\text{Total Area - Area of Streets \& Alleys}}$

TABLE 7

COEFFICIENTS OF CORRELATION AND DETERMINATION
FROM REGRESSION ANALYSES

Equation	Coefficient of Correlation, R	Coefficient of Determination, R^2
1	.982	.965
2	.982	.965
3	.969	.939
4	.982	.964
5	.986	.972
6	.975	.950
7	.948	.898
8	.933	.871
9	.897	.805

A second test was made on the results of the Regression Analysis using "Student's t statistic" (13). The differences between the estimated and observed information were the sample data on which this phase of the analysis was based. A 90 per cent confidence interval for the difference between the means for each equation was developed from the following expression:

$$\bar{d} - t_{.05, D.F.} \; S/\sqrt{N} \leq \mu_D \leq \bar{d} + t_{.05, D.F.} \; S/\sqrt{N}$$

where,

μ_D	=	the true value of the difference between observed and estimated trip productions
$\bar{d}$	=	the mean difference between paired values of observed and estimated trip productions
$t_{.05, D.F.}$	=	the appropriate tabled value from the t distribution for a probability of 0.10 and N-1 degrees of freedom.
S	=	the standard deviation for the differences between observed and estimated trip productions
N	=	the number of observations.

This confidence interval is shown in Table 8.

TABLE 8

TESTS OF SIGNIFICANCE FOR MEAN DIFFERENCE BETWEEN O.D. AND ESTIMATED VALUES

Equation	Average Trips Per Zone		$\frac{\sum_{i=1}^{N}(d_{oi}-d_{ei})}{N}$	Std.Dev. for Diff. Between Obs. and Est. Trips/Zone	90% Confidence Interval for Diff. Between Means		Degrees of Freedom	
	O.D. Survey	Regress. Eq.		S	$d \pm t \, S/\sqrt{N}$		D.F.	$t_{\alpha/2, D.F.}$
1	138.3	138.9	0.69	51.7	-8.91	+10.19	82	1.664
2	215.2	214.8	-0.01	40.5	-11.94	+11.92	32	1.694
3	160.2	162.3	-2.06	64.5	-11.96	+ 7.85	115	1.659
4	102.0	103.3	-1.25	39.0	-8.37	+ 5.87	82	1.664
5	132.0	131.9	0.02	25.1	-7.38	+ 7.42	32	1.694
6	110.5	111.9	-1.34	43.1	-7.98	+ 5.30	115	1.659
7	36.3	37.2	-0.33	23.6	-4.64	+ 3.98	82	1.664
8	83.1	83.1	0.00	26.5	-7.81	+ 7.81	32	1.694
9	49.7	51.1	1.49	33.7	-3.69	+ 6.67	115	1.659

The confidence interval was examined as a test of signifance for the hypothesis that the population mean difference was zero, $\mu_D = 0$. If zero was included within the interval, the differences were not significant. In all equations the hypothesis that $\mu_D = 0$ was accepted since zero was within the 90 per cent confidence interval. Therefore, it may be stated that the estimated trip productions are not significantly different from the observed trip productions when tested at the 90 per cent confidence level.

Figures 3 through 11 show plots of the trip productions from the O. D. survey data versus trip productions estimated from regression equations. Tables 9 and 10 list the O. D. data and the estimated productions and attractions for all trucks in Hutchinson and Pittsburg, respectively. The figures demonstrate graphically the ability of the regression equations to accurately reproduce the observed trip productions. The points will closely approximate a "45° line" for those equations with higher estimating power since points on this "line" will have the same value for estimated trips as for the observed O. D. trips. The band shown in these figures indicates the maximum survey error which may be expected 95 per cent of the time, based on the size of the sample used in the O. D. survey. This expected survey error was determined from research by Sosslau and Brokke (15). This relation was developed to provide a means to estimate the error one could expect with a given sample size and trip volume for O. D. surveys.

FIGURE 3
COMPARISON OF PRODUCTIONS-ATTRACTIONS

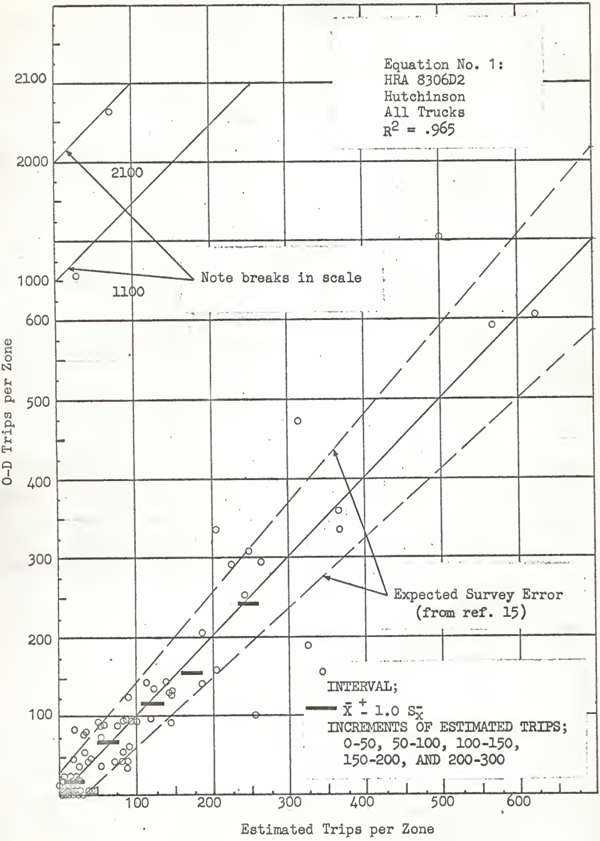


FIGURE 4
COMPARISON OF PRODUCTIONS-ATTRACTIONS

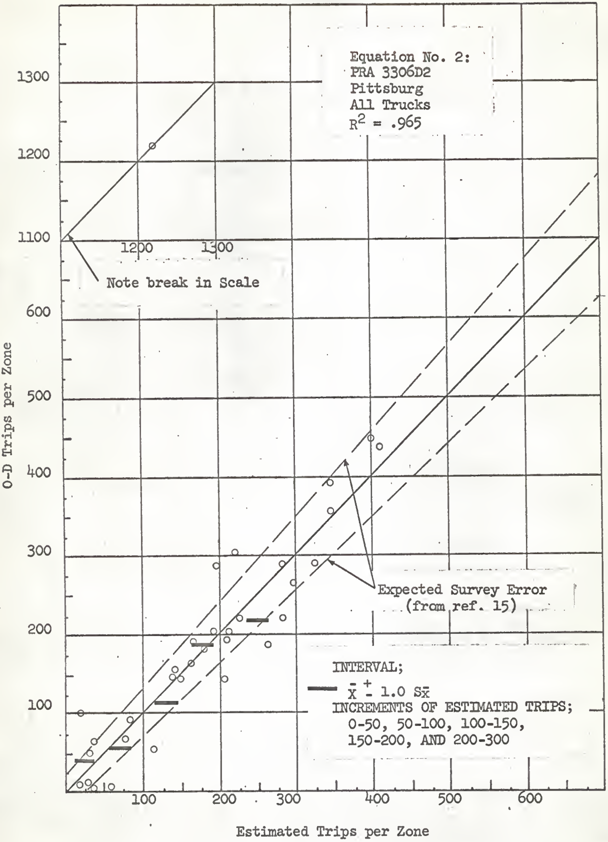


FIGURE 5
COMPARISON OF PRODUCTIONS-ATTRACTIONS

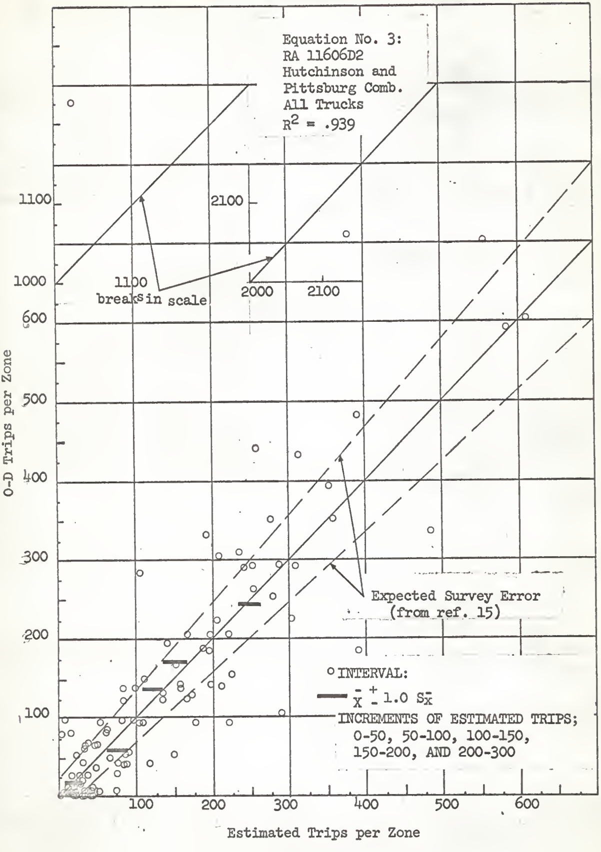


FIGURE 6
COMPARISON OF PRODUCTIONS-ATTRACTIONS

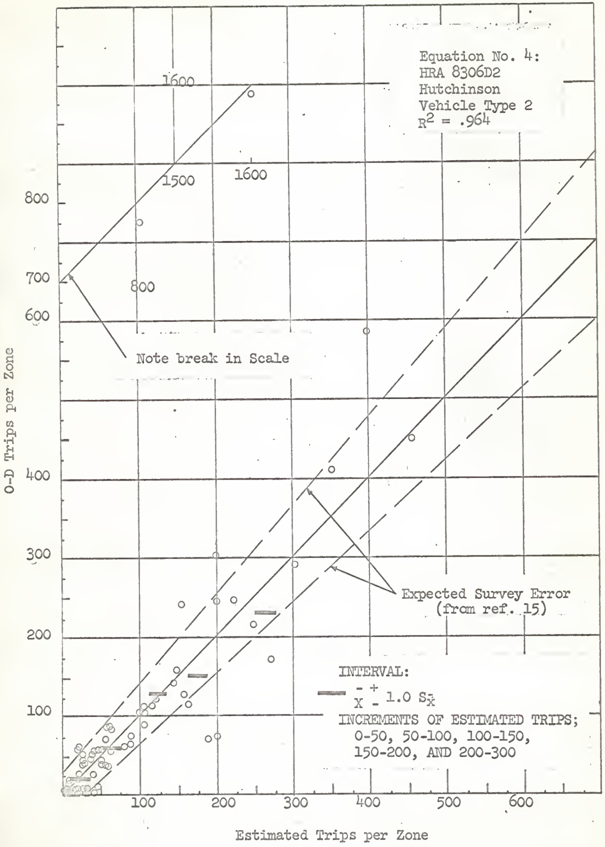


FIGURE 7
COMPARISON OF PRODUCTIONS-ATTRACTIONS

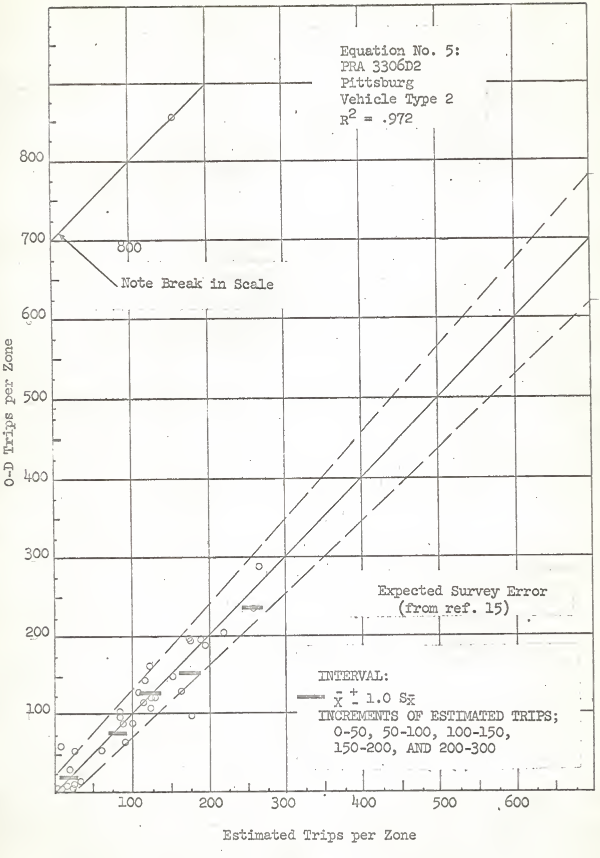


FIGURE 8
COMPARISON OF PRODUCTIONS-ATTRACTIONS

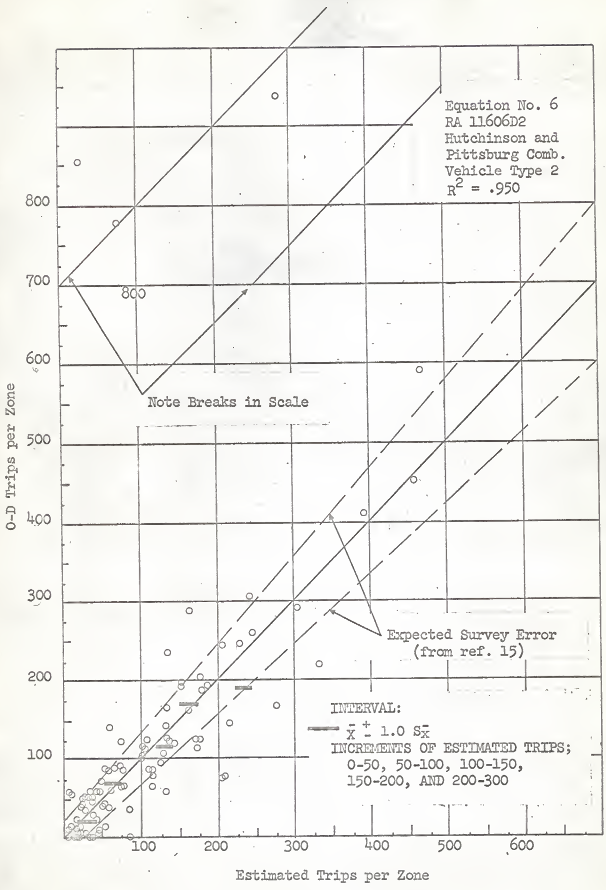


FIGURE 9
COMPARISON OF PRODUCTIONS-ATTRACTIONS

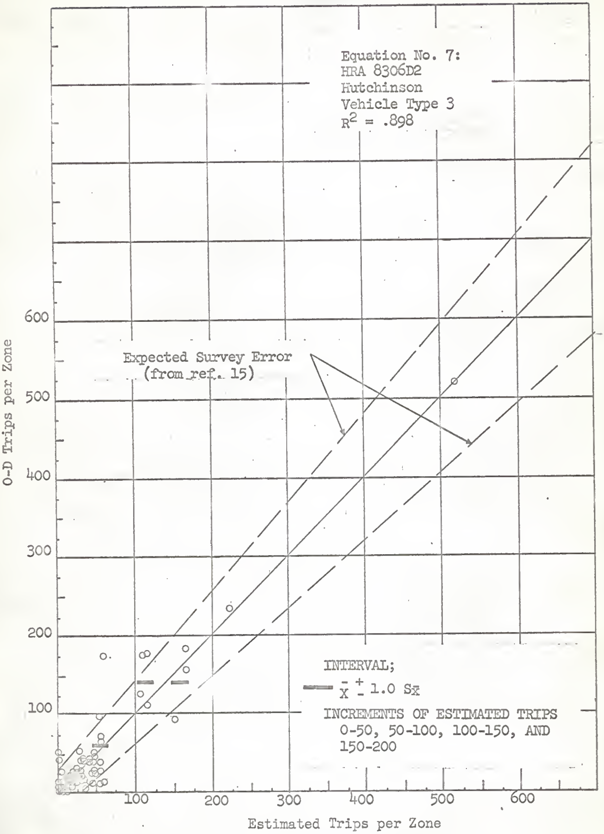


FIGURE 10
COMPARISON OF PRODUCTIONS-ATTRACTIONS

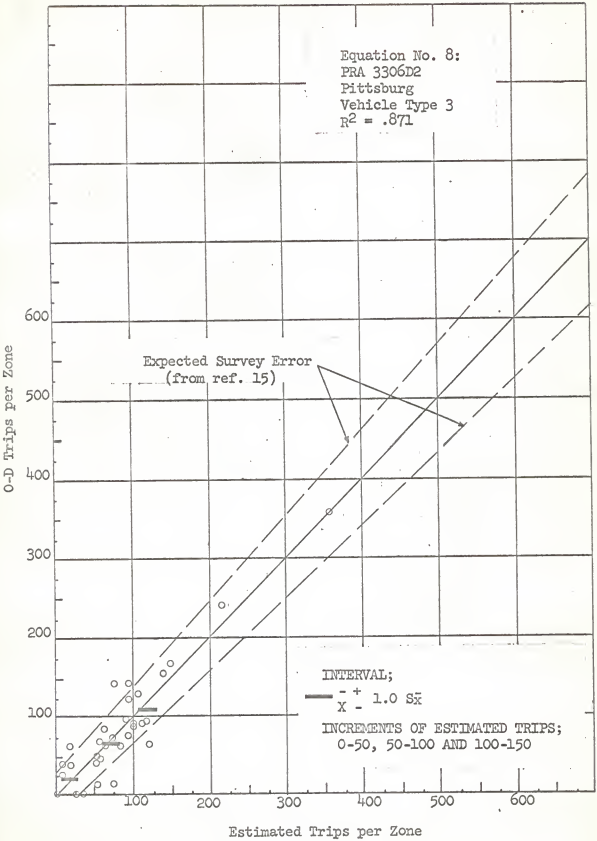


FIGURE 11
COMPARISON OF PRODUCTIONS-ATTRACTIONS

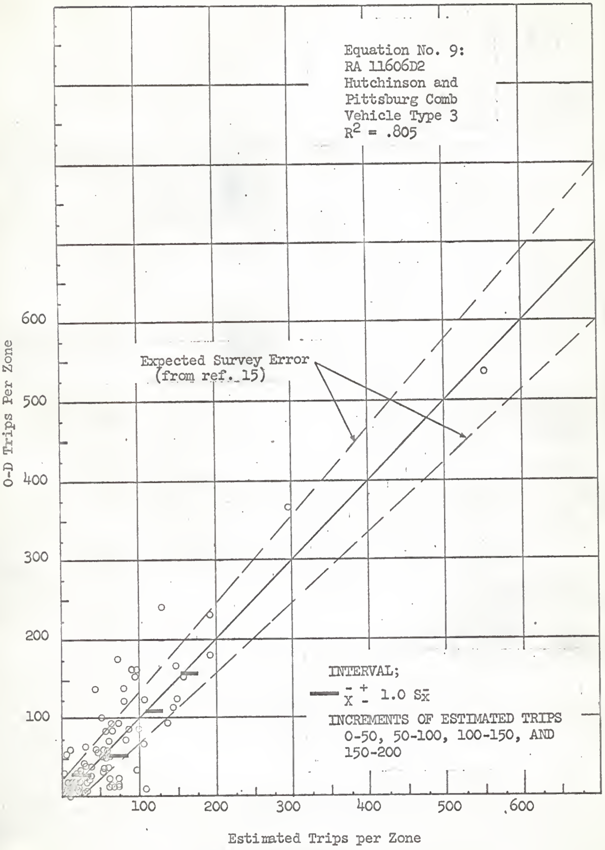


TABLE 9
HUTCHINSON

COMPARISON OF PRODUCTIONS AND ATTRACTIONS FROM O.D.
WITH ESTIMATED VALUES FOR ALL TRUCKS

Dist.	Zone	O.D. Production	O.D. Attraction	Est.
1	12	2082	2066	2074
	13	471	477	313
	50	592	592	519
Sub-Tot.		3145	3135	2906
2	61	121	126	147
	62	132	132	158
	70	5	11	-
Sub-Tot		258	269	305
3	14	186	186	328
Sub-Tot		186	186	328
4	23	137	142	116
	24	99	93	93
	64	296	290	230
Sub-Tot.		532	525	439
5	48	-	-	10
	49	-	-	8
	68	77	82	57
	88	22	22	13
	89	11	11	8
	90	-	-	7
	91	-	-	8
	92	44	49	20
	93	5	-	12
	94	11	11	20
Sub-Tot.		170	175	163
6	59	110	104	252
	60	356	356	363
	73	121	126	144
	74	307	296	269
Sub-Tot.		894	882	1028
7	76	153	148	144
	77	197	203	189
	81	5	5	19
	82	-	-	2
	83	-	-	9
Sub-Tot.		355	356	363

Dist.	Zone	O.D. Production	O.D. Attraction	Est.
8	15	99	99	84
	16	137	142	190
	20	93	93	78
	21	11	16	24
	22	-	-	24
	26	-	-	27
	27	38	38	28
	28	5	16	18
	47	16	16	5
Sub-Tot		399	420	478
9	30	5	5	32
	31	88	88	50
	32	99	99	120
	33	93	93	148
	34	44	44	82
	35	137	132	25
	36	5	5	34
	37	5	5	13
	38	-	-	3
	39	27	22	22
	40	38	33	85
	41	16	22	5
	42	49	49	44
	43	-	-	5
	44	-	-	14
	45	55	55	35
	46	11	11	12
Sub-Tot.		672	663	729
10	17	60	55	81
	18	334	334	368
	52	77	82	71
	54	93	82	22
	55	132	126	93
	56	66	66	91
	78	5	5	43
Sub-Tot		767	750	769
11	53	691	707	503
Sub-Tot		691	707	503

TABLE 9 (Continued)

Dist.	Zone	O.D. Production	O.D. Attraction	Est.	Dist.	Zone	O.D. Production	O.D. Attraction	Est.
12	71	71	71	53	15	65	312	312	257
	72	82	82	57		66	164	164	343
	84	71	71	32		67	77	77	38
	85	44	44	75		69	44	44	40
	86	5	5	22	Sub-Tot.		641	641	774
	87	33	33	54					
Sub-Tot		306	306	293	16	75	247	252	243
						79	5	5	33
13	19	329	334	206		80	5	5	8
	63	592	603	625	Sub-Tot.		257	262	284
Sub-Tot		921	937	831					
					17	57	104	93	100
14	51	1019	1008	1030		58	159	159	202
Sub-Tot		1019	1008	1030	Sub-Tot		263	252	302
15	25	44	44	87					
	29	-	-	9	Total		11476	11474	11525

TABLE 10
PITTSBURG

COMPARISON OF PRODUCTIONS AND ATTRACTIONS FROM O.D.
WITH ESTIMATED VALUES FOR ALL TRUCKS

Dist.	Zone	O.D. Production	O.D. Attraction	Est.	Dist.	Zone	O.D. Production	O.D. Attraction	Est.
1	500	716	710	717	5	932	-	-	-
	501	310	310	311	Sub-Tot		838	844	853
	502	195	198	195					
Sub-Tot		1221	1218	1223	6	620	92	92	85
						720	152	152	158
2	600	168	162	152		721	53	56	55
	601	274	277	248	Sub-Tot		297	300	298
Sub-Tot		442	439	400					
					7	701	69	69	101
3	730	294	294	278		710	79	83	86
	731	139	135	131		711	116	116	125
	740	73	76	73		770	129	132	94
	751	149	152	165		771	125	132	92
Sub-Tot		655	657	647		772	50	50	36
						930	3	3	2
4	632	26	30	26		941	26	23	51
	741	96	92	97	Sub-Tot		597	608	587
	750	142	142	157					
	760	53	53	50	8	610	142	145	140
	761	36	40	34		661	201	201	225
	762	30	30	28		693	76	76	69
	763	86	86	80	Sub-Tot		419	422	434
	910	-	-	11					
	911	3	3	15	9	690	7	7	6
Sub-Tot		472	476	498		691	-	-	3
						692	73	76	66
5	780	125	119	124		700	113	119	164
	781	60	66	59		940	33	26	63
	790	23	26	24		950	99	99	19
	791	-	-	3	Sub-Tot		325	327	321
	792	-	3	3					
	793	13	13	13	10	650	73	63	108
	794	76	76	77		651	66	66	98
	795	109	106	111		660	63	59	72
	800	125	125	122		680	238	234	208
	801	7	3	6		681	119	106	104
	802	7	7	6		682	33	33	30
	803	135	142	131		810	191	195	165
	804	53	53	51		811	-	-	-
	805	26	26	26		960	10	10	27
	920	10	10	34	Sub-Tot		793	766	812
	921	-	-	24					
	931	69	69	39					

TABLE 10 (Continued)

Dist.	Zone	O.D. Production	O.D. Attraction	Est.	Dist.	Zone	O.D. Production	O.D. Attraction	Est.
11	630	145	142	142	12	980	26	23	33
	631	116	112	113		981	198	201	251
	640	53	50	31		990	33	40	23
	641	7	7	-		991	63	56	43
	670	26	26	29		992	10	10	7
	671	69	73	77		993	40	43	27
	672	43	43	47		994	135	135	94
	900	43	46	49	Sub-Tot		505	508	478
	901	30	30	33					
	970	7	7	17	TOTAL		7103	7101	7089
Sub-Tot		539	536	538					

TABLE 11
TABULATION OF THE LOSS IN SUMS OF SQUARES FOR DELETING A VARIABLE

Variable	EQUATION NUMBER 1	2	3	4	5	6	7	8	9
Population	5.14×10^{2}	3.73×10^{3}	4.13×10^{3}	1.60×10^{-3}	1.82×10^{3}	8.23×10^{2}	4.77×10^{2}	3.40×10^{2}	1.32×10^{3}
Dwelling Units	1.27×10^{4}	2.28×10^{3}	8.95×10^{3}	2.91×10^{3}	1.14×10^{3}	3.39×10^{3}	3.25×10^{3}	1.96×10^{2}	1.21×10^{3}
Cars	6.04×10^{3}	2.79×10^{3}	3.83×10^{4}	3.12×10^{3}	1.11×10^{3}	9.33×10^{3}	5.94×10^{2}	3.80×10^{2}	9.59×10^{3}
Jobs	1.43×10^{5}	2.94×10^{4}	1.99×10^{5}	4.56×10^{4}	1.52×10^{4}	7.24×10^{4}	2.70×10^{4}	2.31×10^{3}	3.08×10^{4}
$\frac{1}{\text{Total Area}}$	1.69×10^{3}	1.98×10^{1}	3.53×10^{3}	1.54×10^{3}	3.25×10^{2}	1.96×10^{3}	9.13×10^{0}	1.85×10^{2}	2.66×10^{2}
$\frac{\text{Land Use Residential}}{\text{Total Area}}$	7.01×10^{3}	2.06×10^{4}	7.41×10^{4}	4.43×10^{3}	6.39×10^{3}	2.39×10^{4}	3.13×10^{2}	4.05×10^{3}	1.40×10^{4}
$\frac{\text{Land Use-Public And Industrial}}{\text{Total Area}}$	1.23×10^{4}	2.41×10^{4}	1.03×10^{5}	8.74×10^{3}	8.96×10^{3}	4.10×10^{4}	3.31×10^{2}	3.67×10^{3}	1.44×10^{4}
$\frac{\text{Land Use Commercial}}{\text{Total Area}}$	1.05×10^{4}	8.91×10^{3}	7.75×10^{4}	5.30×10^{3}	3.15×10^{3}	2.74×10^{4}	9.33×10^{2}	1.46×10^{3}	1.30×10^{4}
$\frac{\text{Open Space}}{\text{Total Area}}$	1.33×10^{4}	1.01×10^{4}	9.55×10^{4}	7.52×10^{3}	4.98×10^{3}	3.57×10^{4}	7.95×10^{2}	9.00×10^{2}	1.44×10^{4}
$\frac{\text{Open Space Fact.}}{\text{Total Area}}$	5.54×10^{2}	9.27×10^{3}	2.53×10^{3}	1.53×10^{2}	3.31×10^{0}	5.72×10^{1}	1.35×10^{2}	8.92×10^{3}	1.81×10^{3}

TABLE 11 (Cont.)

EQUATION NUMBER

Variable	1	2	3	4	5	6	7	8	9
Develop. Fact. / Total Area	9.35×10^{2}	7.37×10^{2}	1.21×10^{3}	9.71×10^{2}	6.80×10^{2}	6.51×10^{2}	2.71×10^{-1}	2.83×10^{3}	1.04×10^{2}
Population x Dwelling Units	7.56×10^{3}	2.76×10^{1}	2.32×10^{4}	2.72×10^{3}	8.93×10^{1}	5.60×10^{3}	1.17×10^{3}	1.74×10^{1}	5.85×10^{3}
Population x Cars	1.40×10^{4}	1.24×10^{2}	1.45×10^{4}	4.09×10^{3}	1.85×10^{1}	3.85×10^{3}	2.73×10^{3}	4.65×10^{1}	3.19×10^{3}
Population x Jobs	2.59×10^{-1}	3.15×10^{4}	9.31×10^{3}	1.39×10^{3}	1.26×10^{4}	1.59×10^{3}	1.33×10^{3}	4.27×10^{3}	3.17×10^{3}
Dwelling Units x Cars	8.81×10^{2}	2.12×10^{2}	8.19×10^{1}	2.77×10^{2}	1.38×10^{2}	1.70×10^{2}	1.56×10^{2}	8.02×10^{0}	5.01×10^{2}
Dwelling Units x Jobs	4.29×10^{3}	5.36×10^{2}	2.76×10^{4}	6.52×10^{3}	6.20×10^{1}	3.20×10^{4}	2.20×10^{2}	2.34×10^{2}	1.44×10^{2}
Cars x Jobs	3.31×10^{3}	3.34×10^{4}	5.15×10^{4}	1.21×10^{3}	1.41×10^{4}	2.81×10^{4}	5.23×10^{2}	4.08×10^{3}	3.55×10^{3}

Estimating equations yielding values which fall within these bands are considered to give results as "good" as the original data. Since it was seen by inspection that an extremely high percentage of the points are included within these bands, the accuracy of estimation by the regression equations relative to the quality of the information obtained from O. D. surveys was felt to be good. It should be noted here that the population of zonal trip productions and attractions being estimated by the regression equations was the population derived by expanding the O. D. information and not the actual population which the O. D. survey data estimates.

The trip productions estimated from regression equations were divided into increments of 50 to 100 and the standard deviations for each of these increments was computed. These values were used to compute the standard error of the means for each cell as follows:

$$\text{Standard Error for Means, } S_{\overline{x}} = \frac{S_x}{\sqrt{N}}$$

where,

S_x = standard deviation for individual observations,

N = number of observations for the mean.

The standard error for means, $S_{\overline{x}}$, was used to compute $\overline{x} \pm S_{\overline{x}}$ confidence intervals for the trip productions estimated by regression equations. These confidence intervals are shown as bars, for each cell, in Figs. 3 through 11.

The relatively narrow confidence intervals, and the overlapping of the 45° line by many of the confidence intervals, indicates the power of the regression equations for estimating the zonal productions and

attractions to be very good. Beyond the range where the confidence intervals were computed the location of the plotted points may be compared with the expected survey error, up to 700 trips per zone, to get an indication of the estimating power of the regression equations.

The factors included in the regression equations are listed at the end of Table 6 on pages 29 and 30. Of these factors the jobs per zone parameter proved to be consistently the best indicator both in its pure form and in combination with other factors. The land use factors in combination with the zonal area also were good indicators of the trips produced or attracted per zone. The conclusions on the relative merits of the various variables was made by comparing the relative magnitudes of the loss in sums of squares for deleting the variable. The values for the loss in sums of squares for deleting variables are listed for all equations in Table 11.

Gravity Model Analysis - O. D. Productions and Attractions

The gravity model was applied using various terminal times as listed previously. In comparing the travel time frequency information and the screen lines, the 1.0 minute terminal times for all zones provided the best results. It was also found that combining all trucks into a single group afforded the best reproduction of the O. D. information. Separate travel time factors were developed for the Pittsburg and Hutchinson data using the 1.0 minute terminal times and the grouping of all trucks.

The first test of the results was an examination of the travel time frequency information. Figures 12 and 13 display the graphs for the travel time frequency versus percentage of total trips for both Pittsburg and Hutchinson using the gravity model and indicate the excellent reproducibility of the O. D. survey data by the gravity model. Further, the comparisons of total truck minutes and average travel times indicate that the results are within the required ±5 per cent as can be seen in Table 12. The approximation of the O. D. travel time frequency distribution by the gravity model was felt to be extremely good. The proximity of the plots in Figs. 12 and 13 and the percentages of error for the comparisons in Table 12 bears this out.

Table 12. Comparisons of average travel time and total truck time.

	Average travel time in minutes			Total truck time in minutes		
	O. D. Survey	Gravity Model	% Error	O. D. Survey	Gravity Model	% Error
Hutchinson - All Trucks 1.0 min. terminal times	6.8	6.9	1.5	77,760	79,032	1.6
Pittsburg - All Trucks 1.0 min. terminal times	5.1	5.0	2.0	35,820	35,571	0.7

The screenlines comparison was made on seven separate screenlines for each of the cities. Figures 1 and 2 show the locations of these screenlines on maps of Hutchinson and Pittsburg. The Hutchinson screenlines were the same used in the gravity model research on passenger cars conducted earlier (1). The Pittsburg screenlines were selected dividing the area approximately in half, separating the north, east, south and west quadrants of the city from the remainder of the city, encircling

FIGURE 12
COMPARISON OF TRAVEL TIME FREQUENCY - O-D VS. MODEL
Hutchinson Data - All Trucks - O-D Productions and Attractions

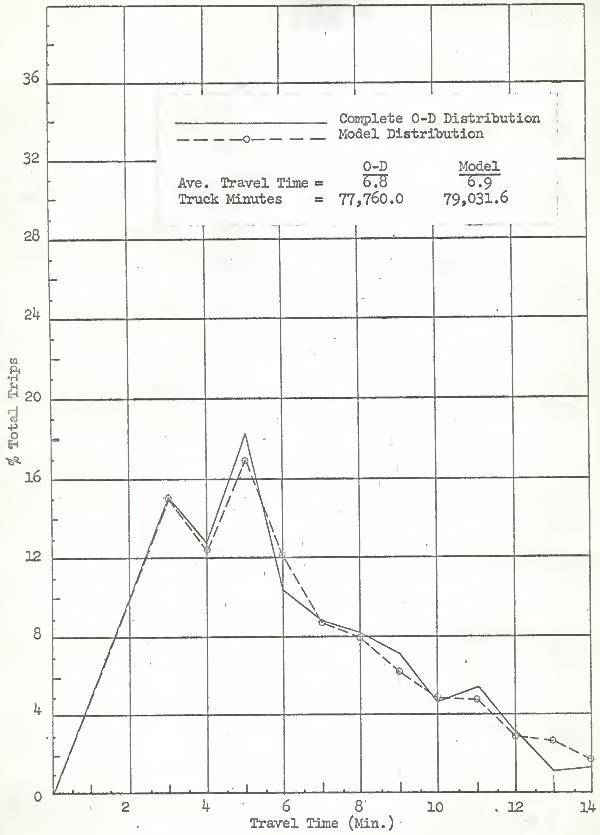
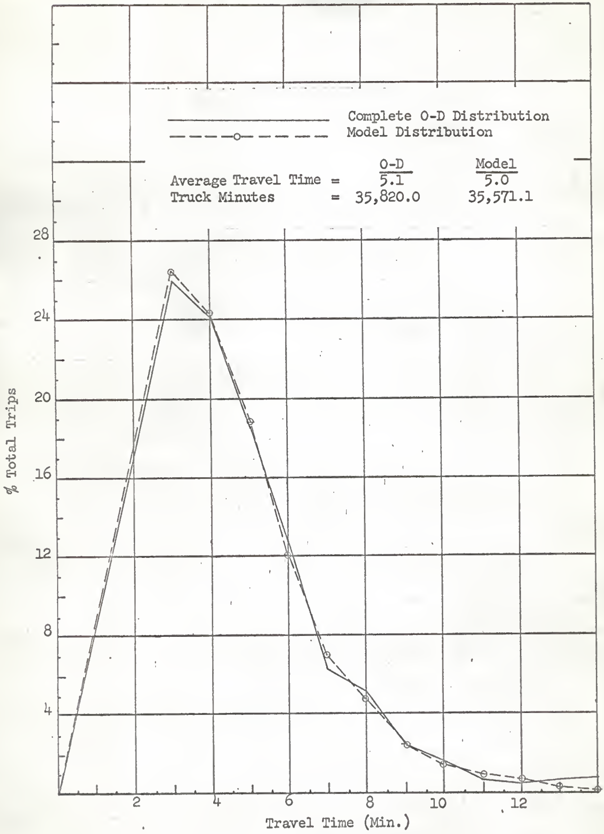


FIGURE 13
COMPARISON OF TRAVEL TIME FREQUENCY - O-D VS. MODEL
Pittsburg Data - All Trucks - O-D Productions and Attractions



the CBD, and separating the Frontenac area from the rest of Pittsburg.

The screenlines comparison indicated that the truck trip configuration as given by the gravity model was a good reproduction of O. D. truck trip distribution. Although the percentage of error in Table 13 was high for some screenlines, the magnitude of the differences between the O. D. and the computed volumes was not large. Standards for the accuracy of screenlines as set forth by the Bureau of Public Roads (16) for traffic studies specify accuracy of ±15 per cent. The comparisons shown in Table 13 meet this for all screenlines with two exceptions. The slight deviation from the standard and the magnitude of the volumes make these acceptable also.

Table 13. Comparisons of O. D. and gravity model volumes crossing screenlines.

Screen-line	Hutchinson			Pittsburg		
	O. D. Crossing Volume	G. M. Crossing Volume	% Error	O. D. Crossing Volume	G. M. Crossing Volume	% Error
1	4, 406	4, 558	3. 4	2, 185	2, 269	5. 3
2	3, 425	3, 435	0. 3	2, 591	2, 563	1. 1
3	3, 467	3, 615	1. 3	1, 515	1, 778	17. 4
4	2, 915	2, 969	1. 9	1, 142	1, 290	13. 0
5	4, 000	3, 859	3. 5	1, 317	1, 430	8. 6
6	1, 085	1, 087	0. 2	2, 105	2, 052	2. 5
7	1, 913	2, 248	17. 5	419	457	9. 1

A third test consisted of the analysis of district to district movements comparing the gravity model and O. D. data. Tables 14 and 15 list the districts and the zones included in each for Hutchinson and Pittsburg, respectively. An examination of the results of this analysis, Tables 16 and 17, shows that in the majority of the volume groups the magnitudes

TABLE 14

HUTCHINSON
DISTRICT AND ZONE TABULATION
FOR DISTRICT TO DISTRICT ANALYSIS

District	Zone
1	12, 13, 50
2	61, 62, 70
3	14
4	23, 24, 64
5	48, 49, 68, 88, 89, 90, 91, 92, 93, 94
6	59, 60, 73, 74
7	76, 77, 81, 82, 83
8	15, 16, 20, 21, 22, 26, 27, 28, 47
9	30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46
10	17, 18, 52, 54, 55, 56, 78
11	53
12	71, 72, 84, 85, 86, 87
13	19, 63
14	51
15	25, 29, 65, 66, 67, 69
16	75, 79, 80
17	57, 58

TABLE 15

PITTSBURG
DISTRICT AND ZONE TABULATION
FOR DISTRICT TO DISTRICT ANALYSIS

District	Zone
1	500, 501, 502
2	600, 601
3	730,731, 740, 751
4	632, 741, 750, 760, 761, 762, 763, 910, 911
5	780, 781, 790, 791, 792, 793, 794, 795, 800, 801, 802, 803, 804, 805, 920, 921, 931, 932
66	620, 720, 721
7	701, 710, 711, 770, 771, 772, 930, 941
8	610, 661, 693
9	690, 691, 692, 700, 940, 950
10	650, 651, 660, 680, 681, 682, 810, 811, 960
11	630, 631, 640, 641, 670, 671, 672, 900, 901, 970
12	980, 981, 990, 991, 992, 993, 994

TABLE 16
ANALYSIS OF DISTRICT TO DISTRICT MOVEMENTS
HUTCHINSON - ALL TRUCKS
O-D PRODUCTIONS AND ATTRACTIONS

Volume Group	Freq.	Total Trips		Average Trips		% Error
		O-D	Model	O-D	Model	
0- 99	122	3,842	4,642	31	38	+20.8
100- 199	21	2,817	2,563	134	122	- 9.0
200- 299	3	664	457	221	152	-31.2
300- 399	2	717	776	359	388	+ 8.2
400- 499	3	1,365	1,165	455	388	-14.6
500- 599	-	-	-	-	-	-
600- 699	1	624	608	624	608	- 2.6
700- 799	-	-	-	-	-	-
800- 899	-	-	-	-	-	-
900- 999	-	-	-	-	-	-
1000- 1499	1	1,136	1,215	1,136	1,215	+ 7.0
1500- 1999	-	-	-	-	-	-
2000- 2999	-	-	-	-	-	-
3000- 3999	-	-	-	-	-	-
4000- 4999	-	-	-	-	-	-
5000- 5999	-	-	-	-	-	-
6000- 6999	-	-	-	-	-	-
7000- 7999	-	-	-	-	-	-
8000- 8999	-	-	-	-	-	-
9000- 9999	-	-	-	-	-	-
10000-999999	-	-	-	-	-	-
TOTAL		11,165	11,426			

TABLE 17
ANALYSIS OF DISTRICT TO DISTRICT MOVEMENTS
PITTSBURG - ALL TRUCKS
O-D PRODUCTIONS AND ATTRACTIONS

Volume Group	Freq.	Total Trips		Average Trips		% Error
		O-D	Model	O-D	Model	
0- 99	58	2,943	3,538	51	61	+20.2
100- 199	13	1,895	1,549	146	119	-18.3
200- 299	5	1,176	1,169	235	234	- 0.6
300- 399	2	750	788	375	394	+ 5.1
400- 499	-	-	-	-	-	-
500- 599	-	-	-	-	-	-
600- 699	-	-	-	-	-	-
700- 799	-	-	-	-	-	-
800- 899	-	-	-	-	-	-
900- 999	-	-	-	-	-	-
1000- 1499	-	-	-	-	-	-
1500- 1999	-	-	-	-	-	-
2000- 2999	-	-	-	-	-	-
3000- 3999	-	-	-	-	-	-
4000- 4999	-	-	-	-	-	-
5000- 5999	-	-	-	-	-	-
6000- 6999	-	-	-	-	-	--
7000- 7999	-	-	-	-	-	-
8000- 8999	-	-	-	-	-	-
9000- 9999	-	-	-	-	-	-
10000- 99999	-	-	-	-	-	-
TOTAL		6,764	7,044			

of the percentage of error were not large with a few exceptions. The percentage of error for the 0-99 group was not felt to be excessive as slight variations in magnitude can cause large percentages of error for this group. The frequency of district to district movements was small for the 200-299 volume so the large error was considered to be non-representative and therefore not important in evaluating the ability of the gravity model to distribute trips accurately. The remainder of these movements were reproduced with acceptable accuracy applying the standard of ±15 per cent error specified for screenlines. Even though one other group was not within these limits, it was felt to be acceptable.

Another important point shown by Tables 16 and 17 was the balance of the signs in the percentage of error columns. These would indicate that the errors were due to both under and over estimation affording the possibility of compensating errors in estimating the overall trip distribution.

The results were not entirely satisfactory in all the tests, however those inconsistencies shown by the comparisons were not large. It is reasonable to assume the small magnitudes of some parameters found from the survey contributed to some of the variation since some zones had such little truck activity.

The travel time factors, F_{ij}, developed using O. D. data zonal trip productions and attractions are listed in Table 18 and given as comparative plots for the study cities in Figure 14.

TABLE 18
TRAVEL TIME FACTORS - ALL TRUCKS
DEVELOPED USING O.D. PRODUCTIONS & ATTRACTIONS

TRAVEL TIME	HUTCHINSON	PITTSBURG
1		
2		
3	1.22	2.54
4	0.96	1.22
5	0.74	0.70
6	0.52	0.46
7	0.36	0.31
8	0.29	0.23
9	0.27	0.17
10	0.26	0.13
11	0.25	0.11
12	0.24	0.10
13	0.23	0.09
14	0.22	0.08
15	0.21	
16	0.20	

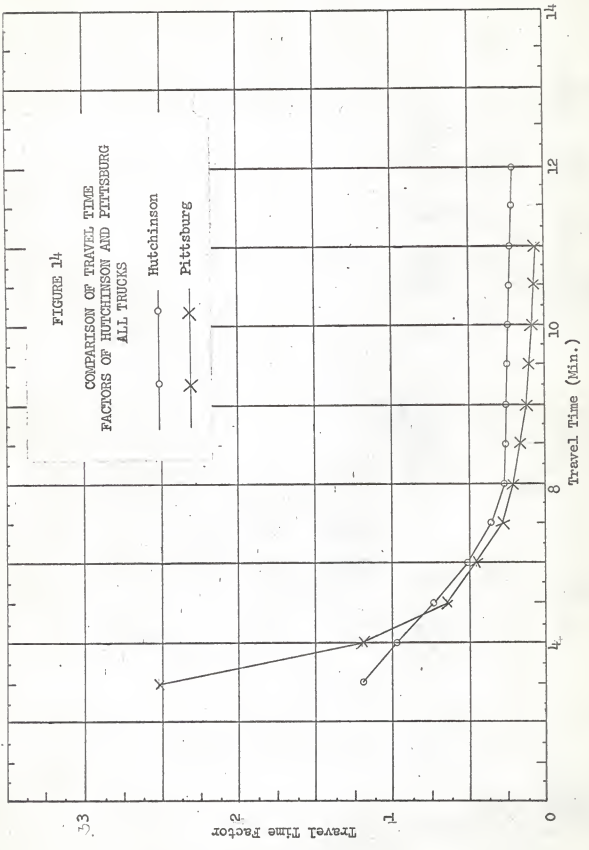


FIGURE 14

COMPARISON OF TRAVEL TIME FACTORS OF HUTCHINSON AND PITTSBURG ALL TRUCKS

Gravity Model Analysis - Estimated Productions and Attractions

The gravity model was applied for the estimated productions and attractions using the 1.0 minute terminal times, all trucks, and the travel time factors found in the runs on the O. D. data. This combination of estimated productions and attractions and the travel time factors from O. D. data as input parameters for the gravity model simulates the manner in which trip distributions would be estimated for the future. The ability to use the travel time factors developed from the application of the gravity model using O. D. data is extremely important for the utility of this method for the estimation of truck trips.

Comparison of the travel time frequency distribution with the O. D. travel time is shown in Figs. 15 and 16. The approximation obtained with this estimated data as shown by the plots for both cities was satisfactory. The other tests of adequacy of reproduction, average travel time and total vehicle minutes, were also within the desired limits of ±5 per cent. Table 19 gives these comparisons. An examination of the figures and the comparisons in Table 19 will show that the approximation of the O. D. travel time frequency by the gravity model was extremely good even when using estimated zonal trip productions and attractions.

FIGURE 15
COMPARISON OF TRAVEL TIME FREQUENCY - O-D VS. MODEL
Hutchinson - All Trucks - Estimated Productions and Attractions

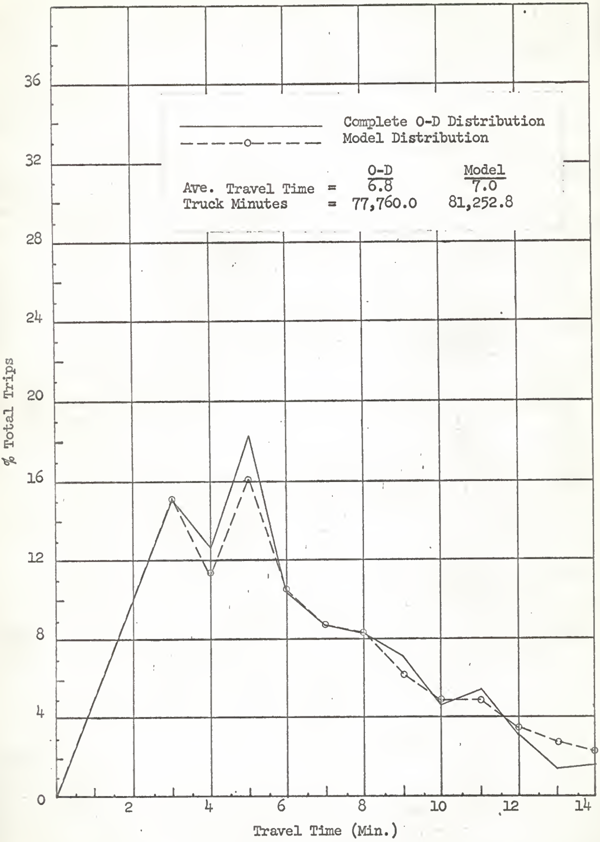


FIGURE 16
COMPARISON OF TRAVEL TIME FREQUENCY - O-D VS. MODEL
Pittsburg - All Trucks - Estimated Productions and Attractions

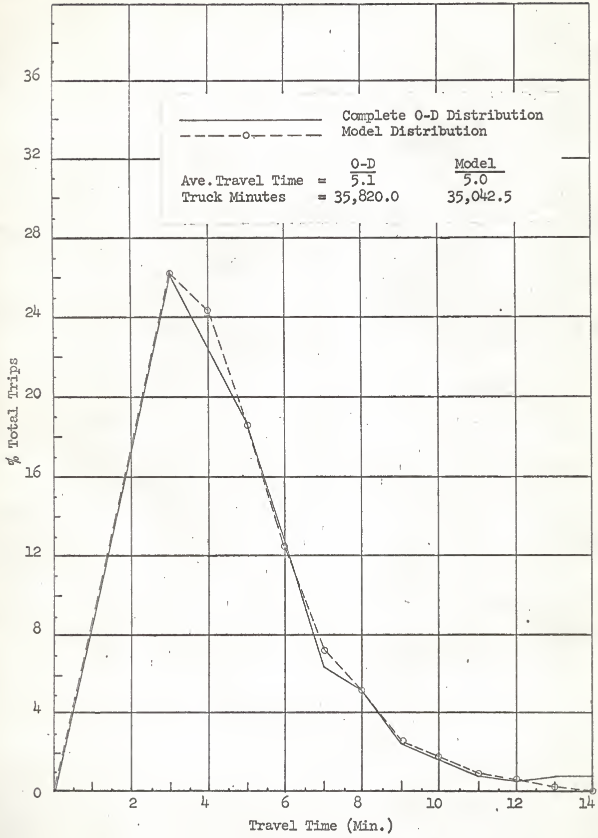


Table 19. Comparisons of average travel time and total truck time.

	Average travel time in minutes			Total truck time in minutes		
	O. D. Survey	Gravity Model	% Error	O. D. Survey	Gravity Model	% Error
Hutchinson	6.8	7.0	2.9	77,760	81,253	4.5
Pittsburg	5.1	5.0	2.0	35,820	35,043	2.2

The screenline comparisons are shown in Table 20. These results were also satisfactory, even though the percentage of error was substantial in some cases, the magnitude of the difference was reasonable. The results from the screenlines were of about the same accuracy as with the O. D. data for productions and attractions. Only two screenlines were in error by more than 15 per cent, and these were not excessive.

Table 20. Comparisons of O. D. and gravity model volumes crossing screenlines.

Screen-line	O. D. Crossing Volume	G. M. Crossing Volume	% Error	O. D. Crossing Volume	G. M. Crossing Volume	% Error
1	4,406	4,545	3.1	2,185	2,301	5.3
2	3,425	3,439	0.4	2,591	2,611	0.8
3	3,567	3,738	4.8	1,515	1,748	15.4
4	2,915	3,123	7.1	1,142	1,243	8.8
5	4,000	3,683	7.9	1,317	1,355	2.9
6	1,085	1,245	14.7	2,105	2,028	3.7
7	1,913	2,240	17.1	419	429	2.4

The analysis of district to district movements is shown in Tables 21 and 22. The results from this comparison are similar to those for the O. D. survey data. The percentages of error were acceptable with two exceptions, the 0-99 and the 400-499 volume groups in Table 21. The percentage of error in the 0-99 group would not be troublesome. The 400-499 group had a significant percentage of error but only includes 3 district to district movements, and the error in estimate amounts to 397 trips.

The results from the gravity model application using the estimated zonal trip productions and attractions were acceptable and, with a few exceptions, accurate enough for use in future prediction of the truck trip distribution. However, two observations should be made at this time which have a bearing on this. The first is that the accuracy of the prediction of truck trips depends largely on the prediction of the future zonal trip productions and attractions which in turn depends on the prediction of the future zonal characteristics. Therefore the future truck trip distribution prediction will be only as good as the prediction of the zonal characteristics. The second is that presently no information is available on the behavior of the travel time factors, F_{i-j}, after the passage of time. At present we must assume these factors remain constant.

TABLE 21
ANALYSIS OF DISTRICT TO DISTRICT MOVEMENTS
HUTCHINSON - ALL TRUCKS
ESTIMATED PRODUCTIONS & ATTRACTIONS

Volume Group	Freq.	Total Trips		Average Trips		% Error
		O-D	Model	O-D	Model	
0- 99	122	3,842	4,906	31	40	+27.7
100- 199	21	2,817	2,519	134	120	-14.2
200- 299	3	664	568	221	189	-14.5
300- 399	2	717	776	359	388	+ 8.2
400- 499	3	1,365	968	455	323	-29.1
500- 599	-	-	-	-	-	-
600- 699	1	624	575	624	575	- 7.9
700- 799	-	-	-	-	-	-
800- 899	-	-	-	-	-	-
900- 999	-	-	-	-	-	-
1000- 1499	1	1,136	1,053	1,136	1,053	- 7.3
1500- 1999	-	-	-	-	-	-
2000- 2999	-	-	-	-	-	-
3000- 3999	-	-	-	-	-	-
4000- 4999	-	-	-	-	-	-
5000- 5999	-	-	-	-	-	-
6000- 6999	-	-	-	-	-	-
7000- 7999	-	-	-	-	-	-
8000- 8999	-	-	-	-	-	-
9000- 9999	-	-	-	-	-	-
10000-999999	-	-	-	-	-	-
TOTAL		11,165	11,365			

TABLE 22
ANALYSIS OF DISTRICT TO DISTRICT MOVEMENTS
PITTSBURG - ALL TRUCKS
ESTIMATED PRODUCTIONS & ATTRACTIONS

Volume Group	Freq.	Total Trips		Average Trips		% Error
		O-D	Model	O-D	Model	
0- 99	58	2,943	3,409	51	59	+15.8
100- 199	13	1,895	1,574	146	121	-16.9
200- 299	5	1,176	1,131	235	226	- 3.8
300- 399	2	750	790	375	395	+ 5.3
400- 499	-	-	-	-	-	-
500- 599	-	-	-	-	-	-
600- 699	-	-	-	-	-	-
700- 799	-	-	-	-	-	-
800- 899	-	-	-	-	-	-
900- 999	-	-	-	-	-	-
1000- 1499	-	-	-	-	-	-
1500- 1999	-	-	-	-	-	-
2000- 2999	-	-	-	-	-	-
3000- 3999	-	-	-	-	-	-
4000- 4999	-	-	-	-	-	-
5000- 5999	-	-	-	-	-	-
6000- 6999	-	-	-	-	-	-
7000- 7999	-	-	-	-	-	-
8000- 8999	-	-	-	-	-	-
9000- 9999	-	-	-	-	-	-
10000-999999	-	-	-	-	-	-
TOTAL		6,764	6,904			

CONCLUSIONS

The following conclusions resulted from this study:

O. D. Survey Data:

1. The truck trip productions and attractions for each zone were found to be essentially equal from the O. D. survey data.

Multiple Regression Analysis:

2. The zonal trip productions and attractions were estimated with acceptable accuracy by the regression equations for use as input for the gravity model.
3. The regression equations, as developed, are expected to satisfactorily estimate future zonal truck trip productions and attractions.
4. The jobs per zone parameter was an extremely good indicator of the trip productions and attractions in the regression estimating equations, singly and in combination with other terms.
5. The ratios of the various general land use areas to the total zonal area were good indicators of trip productions and attractions in the regression equations.

Gravity Model Distribution using O. D. Productions and Attractions:

6. The O. D. survey truck trip distribution was adequately reproduced by the mathematical gravity model when O. D. survey data were used to determine the productions and attractions.
7. Although truck grouping by vehicle type provided satisfactory results, the results obtained using all trucks in one group were better.

8. As one would expect, terminal times did not have a large influence on truck trips. However, the results obtained with 1.0 minute terminal times for all zones were slightly better than other terminal times tested.

9. The travel time factors for the gravity model for Pittsburg varied from those for Hutchinson, with the same vehicle type grouping, terminal times, and source of productions and attractions.

10. The assumption that all zone-to-zone adjustment factors, $K_{i-j's}$, were 1.0 for the gravity model apparently was valid.

Gravity Model Distribution using Productions and Attractions Estimated by Regression Equations:

11. The O. D. survey truck trip distribution was adequately reproduced for planning purposes using estimated productions and attractions from regression equations indicating the validity of using the gravity model for the prediction of future truck trip distributions.

12. The travel time factors developed with the O. D. trip productions and attractions required no adjustment to meet the required standards when the estimated productions and attractions were used as inputs to the gravity model.

13. Full O. D. survey samples for trucks will be required until another suitable method can be devised to determine the travel time frequency distribution.

RECOMMENDATIONS FOR FURTHER RESEARCH

Further research is needed to determine reliable relationships between travel time and travel time factors. Plots made on logarithmic and semi-logarithmic graph paper during the course of research indicated that a straight line does not adequately demonstrate the relationship between these two parameters. Other unknown related factors or effects which are not accounted for elsewhere tended to influence the relation, giving other than straight line plots.

Further examination of the relationship between zonal characteristics and truck trip production and attraction for other cities in an attempt to determine standard relationships would be also of value.

A real need exists to take information from a comprehensive O. D. survey and a land use survey from the past, and apply the gravity model to these data predicting the expected trip distribution for the present in that same city. The results from the gravity model could then be compared with the existing trip distribution as determined by a current O. D. survey. The validity of assumptions which now must be accepted could then be tested.

ACKNOWLEDGMENT

I wish to express my sincere appreciation and deepest gratitude for the direction, encouragement and criticism so kindly given by Dr. Bob L. Smith, Associate Professor of Civil Engineering at Kansas State University. Without his efforts and counsel the culmination of this research would not have been as rapid or complete.

For his guidance and valuable suggestions in the organization and review of this thesis, I would like to extend my sincere thanks to Dr. Jack B. Blackburn, Head of the Civil Engineering Department at Kansas State University.

Many members of the Planning Department and Computer Section, Kansas Highway Commission, were of assistance during the course of the research. In particular, I would like to thank Charles Ault, Arthur Gardner and James Major.

My thanks are also extended to Miss Donna Vialle for her tireless efforts in typing and retyping the research report.

I wish to acknowledge also the sponsorship of this research by the Kansas Highway Commission and the Bureau of Public Roads.

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A GRAVITY MODEL DISTRIBUTION OF
TRUCK TRIPS IN TWO SMALL CITIES

by

ROBERT D. LAYTON

B. S., Colorado State University, 1959

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY

1965

The purpose of this research was to develop a mathematical model (the gravity model) that would distribute internal commercial vehicle trips among the various zones in a city in accordance with existing distributions as measured by origin-destination (O. D.) studies. Once this accord was established the use of the gravity model as a tool for the distribution of future truck trips was investigated.

The data were obtained from the origin-destination surveys and land use studies of two small Kansas cities, Hutchinson and Pittsburg. The studies were conducted in 1959 and 1961, respectively, for the cities mentioned. The trucks were grouped into light, medium and heavy classifications.

In order to carry out the objectives of the research, the study was divided into three phases. These were:

1. The development of equations to estimate the zonal trip productions and attractions from zone characteristics using the multiple regression analysis technique.
2. The use of the O. D. survey trip productions and attractions to test the adequacy of the gravity model to reproduce the truck trip distribution.
3. The use of the trip productions and attractions estimated by the regression equations, and of the travel time factors developed in the previous gravity model application, to test the adequacy of the gravity model to estimate future truck trip distributions.

In the final analysis, it was found that the inclusion of all trucks in one group gave the best results with the applications of the gravity model and afforded satisfactory results in the development of the estimating equations obtained from multiple regression analysis.

The regression estimating equations for all trucks in both Hutchinson and Pittsburg had a coefficient of determination of 0.965 indicating that 96.5 per cent of the observed relationship, between truck trip production and the kinds of variables investigated in this study, was accounted for by the variables contained in the regression equations. The variable, jobs per zone, tended to be the best indicator of zonal trip productions and attractions.

The gravity model application using the O.D. survey data trip productions and attractions, and the application using estimated trip productions and attractions, obtained from multiple regression analysis, both gave satisfactory results. However, to obtain agreement between actual and estimated trip distributions, it was necessary to use different travel time factors for Pittsburg than those for Hutchinson. The final conclusions were that the gravity model could be applied to the distribution of internal truck trips and that future internal truck trip distributions could be estimated using the currently-accepted assumption that the travel time factors would remain constant over the period of time from the date of plan development to the date selected as the design year.